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Objektivní hodnocení posturální funkce břišních svalů a nitrobřišního tlaku

Objective evaluation of postural function of abdominal muscles and intra-abdominal pressure

Disertační práce

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Objektivní hodnocení posturální funkce břišních svalů a nitrobřišního tlaku

Abstrakt

Hlavním tématem této disertační práce je posturální funkce nitrobřišního tlaku, která je důležitým mechanismem při stabilizaci páteře a celého trupu. Nitrobřišní tlak je vytvořen koordinovanou aktivitou mezi bránicí, svaly pánevního dna a svaly břišní stěny. Tlak expanduje do všech stran, stabilizuje a odlehčuje páteř. Jeho zvýšení je důležité zejména během posturálně náročných aktivit, které vyžadují stabilizaci trupu. Nitrobřišní tlak lze hodnotit neinvazivně i invazivně pomocích různých způsobů měření. V rehabilitaci se využívá nejčastěji anorektálních nebo gastroezofageálních sond často v kombinaci s měřením svalové aktivity pomocí elektromyografie. Tyto postupy jsou však pro pacienty nepříjemné, finančně nákladné a náročné na čas. V rehabilitační klinické praxi se běžně hodnotí kvalita trupové stabilizace pomocí palpačního vyšetření aktivity břišní stěny, což je ale vyšetření značně subjektivní. Z výše uvedených důvodu byly sestrojeny nové tlakové senzory umožňující neinvazivní měření tenze břišní stěny a tím i trupové stabilizace. Výzkumná část práce se zaměřuje v rámci pilotního výzkumu na hodnocení posturální aktivity trupového svalstva pomocí dvou typů nových senzorů (přístroje Ohmbelt a DNS Brace) za různých posturálních situací. Hlavním výsledkem předkládané výzkumné práce je korelace aktivity trupového svalstva se změnami nitrobřišního tlaku. Pomocí senzorů jsme dále zjišťovali efekt terapie u pacienta s low back pain či reliabilitu palpačních vyšetření. V rámci intervenční studie jsme také hodnotili efekt terapie využívající trupovou stabilizaci u pacientů s anorektální dysfunkcí a v rešeršní publikaci jsme představili ideální design klinické studie zaměřené na pacienty s low back pain. Tato disertační práce přináší novou možnost objektivního vyšetření posturální stabilizace trupu.

Klíčová slova: nitrobřišní tlak, trupová stabilizace, bolesti bederní páteře, expanze břišní stěny, objektivizace posturálních funkcí, dechový stereotyp

Objective evaluation of postural function of abdominal muscles and intra-abdominal pressure

Abstract

This dissertation deals with an important mechanism of trunk stabilization, the increase of intra-abdominal pressure. Intra-abdominal pressure is created by the coordinated contraction of the diaphragm, along with the abdominal and pelvic floor muscles. Intra-abdominal pressure works in all directions, stabilizing the trunk while reduceing axillary compression of the spine. Intra-abdominal pressure is increased during activities that require demands on the stabilization of the spine. Intra-abdominal pressure and trunk muscle activity can be measured in several different invasive and non-invasive ways. In rehabilitation medicine, anorectal or gastroesophageal probes are most often used to measure intra-abdominal pressure and measurements are often supplemented by evaluation of muscle activation using electromyography. However, these measurements are costly, time consuming and inconvenient for patients. The most common tool for evaluating trunk stabilization in rehabilitation practice is digital palpation of abdominal wall tension. However, this evaluation method is subjective. Therefore, new pressure sensors have been developed that allow non-invasive assessment of abdominal wall tensionand thus also the trunk stabilization. This pilot project focuses on the evaluation of postural activity of the trunk muscles using two types of new sensors (Ohmbelt and DNS Brace devices) in different postural situations. The main result of the presented research is the correlation of trunk muscle activity with intra-abdominal pressure changes. Sensors were used to determine the effect of therapy on patients with low back pain and the reliability of palpation examinations. As part of this project, the effect of therapy using trunk stabilization in patients with anorectal dysfunction was evaluated. A review paper presents an ideal design of a clinical study focused on low back pain patients. This dissertation demonstrates a new possible objective examination of postural stabilization of the trunk.

Keywords: intra-abdominal pressure, trunk stabilization, low back pain, abdominal wall expansion, objectification of postural functions, breathing stereotype

Seznam zkratek

CNS = centrální nervový systém

DNS = Dynamická neuromuskulární stabilizace

m. ES = m. erector spinae

EMG = elektromyografie

HRAM = high resolution anorectal manometry (Anorektální manometrie)

IAP = intra-abdominal pressure (nitrobřišní tlak)

kPa = kilopascal

L(x) = bederní obratel

LBP = low back pain

Lp = bederní páteř

m./mm = musculus, musculi (sval, svaly)

mm Hg = milimetry rtuťového sloupce

MRI = magnetická rezonance

m. OEA = m. obliquus externus abdominis

m. OIA = m. obliquus internus abdominis

PD = pánevní dno

m. RA = m. rectus abdominis

m. TA = m. transversus abdominis

TLS = trigonum lumbale superius

RS = roztroušená skleróza

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1. Úvod

Posturální stabilizace je pro pohyb lidského těla nezbytná (Feldman, 2016). Během jakéhokoliv pohybu působí na naše tělo vnější síly, na které reagujeme pomocí sil vnitřních, realizovaných převážně svalovou aktivitou. Tento jev nazýváme „posturální aktivita" (Hodges et al., 2001). Posturální aktivita je reprezentována stabilizační funkcí bránice, břišních svalů a pánevního dna a jejich schopností vytvořit nitrobřišní tlak (intra-abdominal pressure, dále také IAP) v závislosti na řízení centrální nervovou soustavou (CNS) (Hodges et al., 2005). Posturální funkce těchto svalů je však neoddělitelná od funkce respirační. Při zátěži, např. zdvihání těžkých břemen, se aktivují svaly ohraničující břišní a hrudní dutinu a formují "ohraničený válec", čímž zajišťují stabilitu páteře (Goldish et al., 1994).

IAP se uvnitř břišní dutiny chová jako hydraulický tlak. Je produkován koordinovanou svalovou souhrou mezi bránicí, pánevním dnem (PD) břišními a zádovými svaly. Hodnota IAP se mění podle potřeby respiračních a posturálních nároků (stabilizovat páteř a trup proti vnějším silám a gravitaci) (Cobb et al., 2005; Hodges and Gandevia, 2000). V oboru rehabilitace je IAP často diskutovaným tématem a jeho vliv na posturální stabilitu a vznik bolesti bederní páteře (low back pain - LPB) je častým předmětem vědeckých výzkumů zabývajících se jeho funkcí při stabilizaci a odlehčení páteře (spinal unloading). Je však třeba zdůraznit, že posturálně-respirační funkce trupových svalů je neoddělitelnou jednotkou (Goldish et al., 1994). Poznatků o regulaci IAP se využívá též v problematice pánevního dna či v respirační fyzioterapii. V případě dysfunkce svalového systému, který reguluje IAP, mohou vznikat patologické stavy, které mohou být v klinické praxi podceňovány. Objektivní hodnocení IAP má v jak praxi, tak i v odborných studiích důležité místo. Možnosti hodnocení IAP jsou však stále limitovány (Iberti et al., 1987).

2. Posturální funkce nitrobřišního tlaku

2.1. Anatomické poznatky

Z kostních struktur ohraničují břišní dutinu bederní obratle L1-L5, kost křížová, kost pánevní, kost hrudní a 7.-12. žebro (Čihák, 2016). Břišní dutina obsahuje viscerální orgány a nervově-cévní svazky (Kos 2014). Je kaudálně ohraničena svaly a vazy PD. Kraniálně se nachází bránice, ventrálně musculus (m.) rectus abdominis (RA), laterálně m. transversus abdominis (TA), m. obliquus externus abdominis (OEA), m. obliquus internus abdominis (OIA) a dorzálně páteř spolu se zádovými svaly (zejména musculi quadrati lumborum a extenzory páteře) (Hudák and Kachlík, 2017; Kos, 2014; Sugrue, 1995).

Bránice anatomicky odděluje břišní a hrudní dutinu. Plní roli jak respirační, tak posturální. Skládá se ze 3 částí (pars lumbalis, pars costalis a pars sternalis), které se upínají do části nazývané centrum tendineum, jenž obsahuje minimum kontraktilních vláken a převládá zde vazivová tkáň. Skrze tuto šlašitou část prochází vena cava inferior. Sternální část bránice má začátek ve vazivové pochvě m. RA a na processus xiphoideus. Pars costalis má začátek v oblasti 7.-12- žebra a její vlákna zde přecházejí do vláken m. TA, což anatomicky potvrzuje jejich významnou funkční souvislost. Lumbální část se upíná na bederní obratle (L1-L4) a přes ligamentum arcuatum laterale až na 12. žebro. Skrz pars lumbalis prochází aorta a jícen, což opět poukazuje na funkční souvislost s kardiovaskulárním systémem a rolí bránice jako jícnového sfinkteru (Bitnar et al., 2016). Bránice se díky orientaci svých vláken během kontrakce oploští, čímž zvětší objem hrudní dutiny, tím se sníží nitrohrudního tlak a následně dojde k nasátí vzduchu do plic (Hudák, Kachlík 2017; Čihák 2016).

Jak již bylo zmíněno, v rámci dechové i posturální funkce jsou s bránicí úzce spjaty břišní svaly. Propojují oblast hrudníku s pánví a obklopují břišní dutinu prakticky ze všech stran mimo oblasti páteře. Mají různou orientaci vláken a nacházejí se v několika vrstvách propojených vazivovou tkání. Podílejí se na zvýšení IAP a zajišťují svou aktivitou správné nastavení trupu pro práci bránice. Mezi břišní svaly řadíme m. RA, m. TA, m. OEA, m. OIA, m. pyramidalis, m. cremaster a m. quadratus lumborum (Hudák, Kachlík 2017).

Svaly trupu mají různou schopnost zvyšovat IAP a tím pádem i různou schopnost odlehčit páteř (Daggfeldt and Thorstensson, 1997; Mokhtarzadeh et al., 2012; Stokes et al., 2010). M. TA a m. OIA mají nejvíce horizontální průběh svalových vláken, a tudíž jsou schopni velmi efektivně generovat IAP a odlehčit zejména bederní část páteře. M. OEA má svalová vlákna do 60° sklonu vůči vertikále, což umožňuje za určitých situacích částečný efekt na odlehčení páteře. Svaly s orientací vláken nad 60° (m. ES, m. RA, m. latissimus dorsi) nejsou schopny vytvářet IAP a kvůli jejich vertikálnímu směru vláken mohou zvyšovat axiální zatížení v oblasti páteře (Mokhtarzadeh et al., 2012). Další autoři popisují, že během submaximálních kontrakcí se vždy aktivuje m. TA. Svaly se šikmějším sklonem vláken se podílejí na zvyšování IAP až za maximálního úsilí (Daggfeldt and Thorstensson, 1997).

Pánevní dno kaudálně ohraničuje břišní dutinu v oblasti malé pánve a obsahuje množství drobných svalů, které se podílejí mimo jiné na vytváření a regulaci IAP. Podepírají břišní orgány a zároveň se z důvodu průchodu močopohlavního a trávicího ústrojí podílí na sfinkterové funkci pro tyto soustavy (Hudák, Kachlík 2017; Hodges, Sapsford, Pengel 2007).

2.2. Fyziologické poznatky o nitrobřišním tlaku

Stabilizace trupu je úzce spojena s důležitou vitální funkcí – dýcháním (Bradley and Esformes, 2014; Kang et al., 2016; Park and Lee, 2019). Bránice nezastává pouze úlohu dechového svalu, funguje také jako jícnový svěrač a v neposlední řadě má funkci posturální (Bitnar et al., 2016; Hodges and Gandevia, 2000). Její kontrakce je modulována posturálními i ventilačními nároky (Hodges and Gandevia, 2000). Pracuje-li bránice fyziologicky, centrum tendineum se při kontrakci – nádechu – posouvá kaudálně a vytváří tlakový gradient, který vede vzduch do plic. Při tom se díky aktivitě pánevního dna a břišní stěny zvyšuje tlak v břišní dutině (Talasz et al., 2012, 2011). Břišní dutinu a její obsah lze zjednodušeně představovat jako balon s kapalinou. Při kontrakci stěn balonu (bránice, břišní svaly a pánevní dno) se tlak šiří všemi směry jako by šlo o tekutinu (Christensen and Craft, 2018). V oblasti břišní dutiny se však, na rozdíl od míče, bude zvyšující se IAP snažit unikat v místech s větší poddajnosti břišní stěny, nebo kde není dostatečná kontrakce trupových svalů (Talasz et al., 2012).

Výsledky měření IAP se nejčastěji uvádí v jednotkách mmHg. Hodnota IAP se neustále mění podle aktivit konkrétního jedince. Fyziologická klidová hodnota IAP u zdravých jedinců je 0-7 mm Hg (De Keulenaer et al., 2009; Sugrue, 1995). Tato hodnota se měří vleže ve vodorovné pozici na konci klidového exspiria (Malbrain et al., 2006a). U obézních pacientů nebo v těhotenství bývá tato hodnota vyšší – pohybuje se často mezi 9-14 mm Hg (De Keulenaer et al., 2009; Malbrain et al., 2006b).

Nejdůležitější roli během dýchání má jako primární dechový sval právě bránice. V koordinované aktivitě s břišními svaly a pánevním dnem vytváří svalovou souhru, která mění během dechového cyklu hodnotu IAP. Tyto trupové svaly mění hodnoty IAP i během posturálního zatížení lidského těla, jako je vertikalizace, zvedání břemen a další pohybové projevy (Talasz et al., 2012).

Nádechová fáze dechového cyklu začíná koncentrickou aktivitou bránice vedoucí k jejímu oploštění a pohybem centrální části bránice kaudálním směrem. Tento pohyb má vliv na břišní orgány, které jsou tlačeny směrem do pánve a do stran. Na kaudální posun bránice reaguje břišní svalstvo a svalstvo PD excentrickou kontrakcí, čímž se břišní stěna a pánevní dno mírně vyklenují směrem ven z trupu. Nitrohrudní tlak se sníží, (dojde k nasátí vzduchu do plic) a naopak tlak v břišní dutině stoupá (Talasz et al., 2012, 2011). Během klidového výdechu bránice relaxuje a vrací se kraniálně. Břišní stěna spolu s pánevním dnem se díky předpětí z předchozí nádechové fáze vrací zpět a objem břišní dutiny se zmenšuje. Během silového výdechu dochází ke koncentrické aktivaci břišních svalů a svalů pánevního dna, čemuž excentricky ustupuje bránice a zvyšuje se IAP (Kim and Lee, 2013; Talasz et al., 2012). K největšímu nárůstu IAP dochází při kašli ve stoji (107,6 mm Hg) a při skoku (171 mm Hg). Průměrné hodnoty při stání a sezení jsou 20 a 16,7 mm Hg. Aktivity, jako je tzv. bicepsový zdvih s činkou vážící 4.5kg, nebo pokrčení v kolenou, zvyšují IAP zřetelně méně (25,5 a 20,6 mmHg) (Cobb et al., 2005).

2.3. Vliv nitrobřišního tlaku na stabilitu páteře

Již v roce 1923 Keith začal zkoumat posturální funkci IAP během zatížení páteře (Keith, 1923). Následovali ho v roce 1942 Bradford a Spurling, kteří změřili, že aktivita mm. erectores spinae může během pohybu vytvořit na páteř zátěž až 680 kg (Bradford and Spurling, 1945). V roce 1957 provedl Bartelink zátěžové testy na meziobratlové ploténky. Zjistil, že strukturální změny na meziobratlových ploténkách vznikaly již při zatížení 136 kg (Bartelink, 1957). Vliv zvýšení IAP během zdvihání břemene podrobně popsal také Davis v roce 1959 (Davis, 1959). Z těchto studií mimo jiné vyplývá, že pokud by neexistovaly žádné kompenzační mechanismy, které umožňují snížit zatížení páteře, snadno by docházelo k jejímu poškození, a to především v oblasti intervertebrálních disků, během jakéhokoliv namáhavého pohybu. Přelomové studie publikoval Hodges et al., kde potvrdil, že pouhý IAP bez jakékoliv aktivity trupového svalstva zvyšuje stabilitu bederní páteře, chrání ji před excesivním zatížením, snižuje axiální kompresi páteře a pomáhá rozložit zatížení na větší část těla (Hodges et al., 2005).

Aktivita bránice zvyšuje tlak v břišní dutině. Následkem toho má obsah břišní dutiny tendence se pohybovat laterálně a kaudálně, čemuž brání kontrakce břišních svalů a svalů pánevního dna (Chaitow et al., 2014; Hodges, 1999; Hodges and Gandevia, 2000). IAP je vlastně hydraulický tlak efektivní ve všech směrech, stabilizující trup a snižující axiální zatížení během aktivit, které mají zvýšené nároky na stabilizaci páteře jako např. zdvihání těžkých břemen (Cobb et al., 2005; Grillner et al., 1978). Aktivita trupového svalstva udržuje všechny segmenty páteře během pohybu v biomechanicky neutrální pozici (Bartelink, 1957). Pánev a bederní páteř jsou vždy reflexně stabilizovány již před začátkem pohybu končetin (Aruin and Latash, 1995; Hodges et al., 2000; Hodges and Richardson, 1997). Tento „feed forward" mechanismus stabilizace, tedy určitá adjustace pohybu, je zajištěn právě svalstvem trupu (Wallden, 2017).

I když je fenomén nitrobřišního tlaku důležitým a často studovaným tématem v oblasti rehabilitace, jeho specifická funkce a konkrétní role stále není detailně objasněna (Arjmand and Shirazi-Adl, 2006; Stokes et al., 2010). Překážkou při výzkumech zaměřených na IAP je problematika měření v experimentálních podmínkách in vivo. I když byl již mnoha autory popsán pozitivní efekt IAP na stabilitu páteře, stále přetrvává problém objektivizace a měření IAP (Stokes et al., 2010). Několik studií sice prokázalo souvislost mezi zvýšením IAP a stabilitou páteře (Cholewicki et al., 1999; Hodges, 1999; Stokes et al., 2011; Hodges et al., 2005), ale stále není zcela jasné, zda právě zvýšení IAP je procesem zajišťujícím mechanickou podporu páteře, či je to sama aktivita břišních svalů (Talasz et al., 2011; Hodges et al., 2005).

Hodges et al. ve svých studiích prokázal, že tuhost bederní páteře během různých pohybů se zvyšuje v závislosti na zvýšení IAP, a to i bez simultánní aktivity trupového svalstva. Předpokládá, že IAP je pro CNS výhodným nástrojem, jak zvýšit stabilitu páteře ve všech směrech (Hodges et al., 2005). Výsledky Hodgese potvrdil Stokes et al. (Stokes et al., 2010). Hodges et al. však na rozdíl od ostatních popsal také proces, kdy crura diafragmatica svou kontrakcí způsobují přímou trakci v ose bederní páteře v oblastech jejich úponu, což podporuje efekt IAP (Hodges et al., 2005). McGill et al. uvádí, že nárůst IAP zvyšuje stabilitu bederní páteře prostřednictvím eliminace rotace a translačního pohybu mezi obratli (McGill and Norman, 1987). Výše uvedení autoři se shodují, že IAP pomáhá udržení správné pozice pohyblivých částí páteře, a to minimalizací či úplnou eliminací drobných pohybů způsobených střižnými silami v oblasti facetových kloubů. Tato hypotéza může vysvětlit fenomén, kdy pacienti s bolestí bederní páteře při bolestivém pohybu zadržují dech a zvyšují IAP (Aruin and Latash, 1995; McGill and Norman, 1987).

Arshad at al. vytvořil biomechanický model trupu, který ukázal snížení kompresivních sil v oblasti páteře a zároveň sníženou potřebu aktivity okolních svalů (Arshad et al., 2016). Někteří autoři se naopak domnívají, že příliš vysoké hodnoty IAP, které vznikají například při Valsalvově manévru, zvyšují zatížení páteře z důvodu nadměrné aktivace svalů trupu (Mokhtarzadeh et al., 2012). Naopak Stokes at al. přišel s tvrzením, že velké kompresní síly vytvořené aktivitou svalů trupu jsou kompenzovány trakčním vlivem IAP na páteř. Prokázal to na biomechanickém modelu páteře, kde zvýšení IAP snížilo zatížení páteře (Stokes et al., 2010). Hodges at al. zase popsali, jak IAP tvoří trakční moment díky silám, které tlačí kaudálně do pánevního dna a kraniálně do bránice (Hodges et al., 2005). Trakční schopnost zvýšeného IAP je doprovázena aktivitou flexorů a extenzorů trupu, které pomáhají ve stabilizaci páteře (Hodges et al., 2005). Další autoři popisují, že díky trakční schopnosti IAP není potřeba tak vysoké aktivity extenzorů páteře pro vyvážení aktivity flexorů (Daggfeldt and Thorstensson, 1997). Toto tvrzení podporuje i Cholewicki et al., s tvrzením, že se při aktivitách vyžadující extenzi trupu (zvedání břemen, výskok) zvyšuje IAP a vytvoří tak potřebnou stabilitu trupu bez nutnosti nadměrné aktivity extenzorů páteře (Cholewicki et al., 1999). Za ideální situace by měl být průřez trupu v horizontálním rovině co největší, což zajistí dostatečný přenos sil, a tak i ochranu pro páteř. Bránice a pánevní dno tudíž musí pracovat proti sobě (Daggfeldt and Thorstensson, 1997). Je proto důležité, že IAP udržuje kruhovitý průřez břišní dutiny, čímž brání ve zkrácení svalů trupu a jejich kolapsu do břišní dutiny, což by omezilo schopnost kontrakce těchto svalů (McGill and Norman, 1987).

Excesivní selektivní aktivita jednotlivých břišních svalů může způsobit snížení aktivace ostatních břišních svalů a negativně ovlivnit stabilizaci páteře (Stokes et al., 2011). Vhodný tonus a aktivace břišní stěny tak, aby fungovala jako jedna harmonická jednotka se svalstvem pánevního dna, je kritickou stabilizační složkou, která optimalizuje tlak na břišní orgány, čímž napomáhá expanzi dolního hrudního koše pro dýchání (Wallden, 2017). Tedy nejen velikost aktivace břišní stěny, ale také typ koaktivace (excentrická vs. koncentrická) hraje důležitou roli při správné trupové stabilizaci. Při posturální zátěži zvýší bránice svým kaudálním pohybem tlak v břišní dutině a jelikož je její obsah nestlačitelný, břišní stěna a pánevní dno musí reagovat excentrickou kontrakcí. Nedostatečná expanze nebo koncentrická aktivace břišních svalů může narušit posturální stabilizační funkci (Hodges and Richardson, 1999; Kalpakcioglu et al., 2009; Kolar et al., 2010).

3. Patologie nitrobřišního tlaku

Posturální funkce je s pohybem a lokomocí velmi úzce spjata: mobilita a stabilita tvoří funkční jednotku, která je pod stálou kontrolou CNS (Ivanenko and Gurfinkel, 2018). Podle některých studií se zdá, že LBP je často spojená s narušenou či změněnou funkcí trupových svalů (Hemming et al., 2019; Jung et al., 2020; Lin et al., 2018). LBP je přitom jedním z hlavních problémů veřejného zdraví způsobující disabilitu se značnými zdravotními a socioekonomickými následky, a to v celosvětovém měřítku (Hoy et al., 2012). LBP je také jeden z nejčastějších důvodů návštěvy lékaře a nezřídka je příčinou vystavení pracovní neschopnosti, jelikož postihuje jedince v produktivním věku (Bonetti et al., 2005; Jenkins, 2002). Insuficientní stabilizace bederní páteře má většinou neurologický či muskuloskeletální původ (Barr et al., 2005; Kuukkanen and Mälkiä, 2000; Tsao et al., 2010).

Neideální koordinace posturálního svalstva a deficit ve stabilizační funkci je považován za důležitý etiologický faktor v případě poruch páteře spojených s bolestí zad jako jsou např. spondyloartróza, výhřez meziobratlového disku či spondylolistéza (Cresswell et al., 1994; Hodges, 1999; Tsao et al., 2010). Komplex bederní páteře je adaptován ke schopnosti nést externí zátěž. Tlak je přenášen do pevných těl obratlů a relativně elastických disků. Excesivní mechanické zatížení však vede k poškození těchto struktur (Adams and Roughley, 2006). Výsledky studií potvrzují, že abnormality v řízení motoriky mohou být nejen příčinou LBP, ale i jejím důsledkem (Hodges et al., 2003; Nelson-Wong and Callaghan, 2010). Porucha posturální kontroly a zpoždění reakčního času trupového svalstva je předpokladem pro vznik patologie v bederní páteři. Tato porucha může být významným rizikovým faktorem pro vznik poranění bederní páteře (Cholewicki et al., 2005). Klinicky je insuficientní aktivace latero-dorsální části břišní stěny (tedy v oblasti trigonum lumbale superius - TLS) a spodní části břišní stěny přímo nad třísly častým nálezem u pacientů s LBP (Frank et al., 2013; Kobesova et al., 2016).

S IAP a trupovou stabilizací úzce souvisí i dysfunkce pánevního dna. Zvýšení tlaku intra-vaginálně časově předchází zvýšení IAP, což naznačuje zvýšení aktivity svalů pánevního dna ještě před nárůstem IAP jako odpověď na posturální zatížení (Hodges et al., 2007; Sapsford and Hodges, 2001). Fyziologicky by svalová aktivace pánevního dna měla předcházet zvýšení IAP z důvodu udržení kontinence, udržení pozice pánevních orgánů, ale též pro zajištění stability páteře (Hodges et al., 2007; Madill and McLean, 2006; Sapsford and Hodges, 2001). Dysfunkce komplexu pánevního dna je často součástí neideální globální posturální koaktivace, nejenom lokální poruchou svalů PD. Proto při neideálním zapojení posturálních svalů u pacientů s LBP je důležité vyšetřit a terapeuticky ovlivnit i svaly pánevního dna, které mají významnou funkci ve vztahu k IAP a stabilizaci bederní páteře, jak potvrdil například Junginger et al. (Junginger et al., 2010).

Na IAP musíme pohlížet i v kontextu jiných tělesných systémů než jenom pohybového aparátu. Akutně, nebo i dlouhodobě nefyziologicky zvýšená hodnota IAP je nazývána jako intra-abdominální hypertenze (Smit et al., 2016). Tato situace patologicky ovlivňuje mnoho tělesných systémů jako například gastrointestinální, respirační, kardiovaskulární nebo renální (Christensen and Craft, 2018). Jedná se o klinicky závažný stav, který často pozorujeme u chronicky nemocných pacientů nebo u pacientů na jednotce intenzivní péče (De Waele et al., 2011). Zvýšený IAP může vést ke vzniku kýly, gastroesofageální refluxní choroby jícnu, hemoroidů, výhřezů v pánevních orgánů, stresové inkontinenci a mnoha dalších patologických stavů (Bitnar et al., 2016; Noblett et al., 1997; Sanchez and Chinn, 2011; Schaffer et al., 2005).

Ovlivnění nitrobřišního tlaku ve smyslu trénování jeho nárustu je častým přístupem v terapii LBP a v silovém tréninku (Aleksiev, 2014; Lee et al., 2014; Tayashiki et al., 2015). Opatrnost s přílišným zvyšováním IAP by měla být v případě, že pracujeme s pacienty po břišních operacích, s kýlou nebo u inkontinence a prolapsů PD (da Silva Borin et al., 2013). Zvýšení IAP zvyšuje následně i krevní tlak, což může být rizikové například u pacientů s hypertenzí nebo pro pacienty se srdečním selháním, kdy by se kvůli vyššímu tlaku v aortě zvýšily nároky na práci levé srdeční komory (Hackett and Chow, 2013; Sugerman et al., 1999). Následkem zvýšení tlaku v břišní dutině se i snižuje návrat žilní krve z dolních končetin, což může zhoršovat otoky v této oblasti. Prudké zvýšení IAP může u spinálních pacientů vyprovokovat autonomní dysreflexii. V neposlední řadě, při zvýšení IAP se následně zvyšuje i intrakraniální tlak, což může být nebezpečné například pro pacienty s rizikem hemoragické cévní mozkové příhody (McGill and Norman, 1987). Terapeutickým cílem by mělo být spíše optimalizace regulace a distribuce IAP než absolutní zvýšení hodnot IAP.

4. Využití nitrobřišního tlaku v terapii

Dechový stereotyp ovlivňuje koordinaci trupového svalstva a modifikuje pohyb, a proto specifický trénink dechového stereotypu tvoří klíčovou část řady cvičebních protokolů zaměřujících se na stabilizaci trupu (Bradley and Esformes, 2014; Kang et al., 2016; Park and Lee, 2019). Pacienti s LBP často vykazují suboptimální respirační parametry a je u nich popsán pozitivní efekt dechových cvičení (Anderson and Bliven, 2017; Calvo-Lobo et al., 2019; Janssens et al., 2015; Shah et al., 2019).

Poruchy ve stabilizaci bederní páteře jsou především původu svalového a neurogenního, a proto mívá léčebný efekt vhodně zvolená fyzioterapie a trénink motorického řízení, které navodí správnou koaktivaci mezi trupovými svaly (Barr et al., 2005; Kuukkanen and Mälkiä, 2000; Tsao et al., 2010). Cvičení zaměřené na stabilizaci trupu a bederní páteře se využívají nejen v léčbě, ale i v prevenci LBP (Horsak et al., 2017). Kromě terapie LBP se nácvik trupové stabilizace využívá při léčbě dalších muskuloskeletálních poruch (Huxel Bliven and Anderson, 2013).

Selektivní aktivace izolovaných skupin břišního svalstva signifikantně nezvyšuje stabilitu páteře (Stokes et al., 2011). Proto by se posturální trénink měl zaměřit na globální koordinaci všech svalů účastnících se stabilizační funkce a regulace IAP. Naopak, cílený trénink zaměřující se izolovaně na jednotlivé svaly může být kontraproduktivní (Stokes et al., 2011). Své místo má IAP i v silovém tréninku, kdy napomáhá zajišťovat stabilitu páteře a udržet správné nastavení segmentů během zátěže a působí tak preventivně na rozvoj bolestí z přetížení či poranění (Hackett and Chow, 2013).

Nácvik kontroly nitrobřišního tlaku se využívá i v terapii pánevního dna. Koordinovaná aktivita PD během zvýšení tlaku v břišní dutině má za následek stlačení uretry a kraniální posun PD v reakci na tlačení obsahu břišní dutiny do malé pánve. Správně instruované zvýšení IAP nemusí tedy znamenat zhoršení inkontinence, ale může mít naopak terapeutický efekt (Talasz et al., 2012).

Například pacienti s roztroušenou sklerózou (RS) mají celkově sníženou pohybovou aktivitu včetně špatné funkce pánevního dna projevující se inkontinencí moči i stolice. Proto bývá těmto pacientům doporučena kromě jiných přístupů i fyzioterapie zaměřená na nácvik správného tonu a koordinace svalů pánevního dna a na jejich aktivaci v rámci komplexního nácviku trupové stabilizace (Motl et al., 2017; Newsome et al., 2017; Saldana Ruiz and Kaiser, 2017). Jedním z přístupů k dysfunkci pánevního dna u RS pacientů může být metoda Dynamické neuromuskulární stabilizace (DNS), kdy je terapie cílená na správnou trupovou stabilizaci i v situacích jako je kašel, dřep, skákání, zvedání zátěže a v dalších situacích, které mohou být spojeny se stresovou inkontinencí (Frank et al., 2013; Kobesova et al., 2016; Kovari et al., 2021).

5. Možnosti objektivizace nitrobřišního tlaku

80 % západní populace se během života setká s bolestí dolní části zad (Alhowimel et al., 2018). K tomu, abychom LBP správně léčili a dosáhli dlouhodobých výsledků, je nutné umět objektivně hodnotit trupovou stabilizaci. V klinické praxi je důležité hodnotit kvalitu posturální stabilizace a objektivně hodnotit schopnost pacienta regulovat IAP v posturálně zátěžových situacích. Nicméně objektivní hodnocení posturální stability trupu stále není jednoznačně definované a běžně používané. Evidence based data pomáhají nastavit optimální léčebný plán, hodnotit terapeutické výsledky, výsledky autoterapie a porovnávat efekt různých léčebných přístupů. Monitoring a trénink posturální stabilizace hraje roli také ve sportovní oblasti, kde figuruje při léčbě a prevenci bolestí zad z přetížení a zároveň napomáhá zlepšit sportovní výkon (Akınoğlu and Kocahan, 2019; Mckeon et al., 2008; Zech et al., 2014).

Jak již bylo zmíněno, IAP účinně stabilizuje páteř a jeho hodnocení v rámci posturální stabilizace je zásadní součástí klinického vyšetření jedinců s muskuloskeletálními obtížemi. Z výsledků publikovaných studií vyplývá že IAP koreluje s posturální stabilitou, a proto jeho vyšetření může ozřejmit kvalitu posturální stabilizace (Cresswell, 1993; Hodges, 1999; Hodges et al., 2005).

Posturální aktivita svalů trupu může být hodnocena mnoha způsoby, např. pomocí ultrasonografie, elektromyografie, tedy nepřímo pomocí hodnocení funkce zúčastněných svalů, nebo přímým měřením IAP (Brown and McGill, 2010; Essendrop et al., 2002). Tyto přístupy umí měřit velmi přesně jak aktivitu konkrétního svalu, tak přímo IAP. Většina těchto metod se ale v rehabilitaci využívá pouze pro výzkumné účely, jelikož měření jsou subjektivně nepříjemná, časově a technicky náročná a výsledky se obtížně vyhodnocují. Tenzi břišní stěny jako následek posturální aktivity můžeme vyšetřovat palpací, která bohužel vykazuje nízkou senzitivitu a přesnost pro hodnocení IAP (Elgueta-Cancino et al., 2014; Frank et al., 2013; Kirkpatrick et al., 2000; Kobesova et al., 2020, 2016). Měření obvodu trupu se také ukázalo jako nepřesná metoda s nízkou reliabilitou (Triffoni-Melo et al., 2019).

Jelikož je lidská postura dynamický proces, potřebujeme nástroj, který bude schopen hodnotit IAP a svalovou stabilizaci trupu v různých posturálních situacích. Dále je důležité zkombinovat klinické vyšetření s objektivním hodnocením zmíněné aktivity.

5.1. Klinické vyšetření

Nejběžnější způsob jak v rehabilitaci hodnotíme posturální stabilizaci trupu je subjektivní klinické vyšetření. Vyšetřující při něm palpuje pomocí prstů kvalitu a symetrii břišní stěny během aktivace trupové stabilizace a tím nepřímo hodnotí IAP (Elgueta-Cancino et al., 2014; Jacisko et al., 2020; Kobesova et al., 2020; Shamsi et al., 2015). Podkladem této metody jsou studie, které popisují rostoucí tuhost břišní stěny s rostoucím IAP (Tayebi et al., 2021; van Ramshorst et al., 2011). Jeden z konceptů, který se zaměřuje na definici optimální postury a využívá sadu funkčních testů k posouzení postury je Dynamická neuromuskulární stabilizace (DNS) (Kobesova et al., 2020).

Palpace se většinou soustředí na oblast nad tříselným vazem a na oblast TLS (Kobesova et al., 2020). Stejné oblasti trupu pro hodnocení aktivity břišní stěny ve vztahu k IAP využívali i další autoři (Kumar et al., 2012; Malátová et al., 2013; Novak et al., 2020). V těchto oblastech břišní stěny nacházíme pouze úpony plochých břišních svalů a tudíž je zde dobře přístupná břišní dutina a větší pravděpodobnost, že tlak palpovaný či monitorovaný senzory je IAP, nikoliv lokální aktivace jednoho svalu (Grevious et al., 2006). Neideální aktivaci v těchto místech můžeme velmi často nalézt u pacientů s LBP (Frank et al., 2013; Kobesova et al., 2016).

5.2. Testování nitrobřišního tlaku přístrojově

5.2.1. Transperitonealní měření

Nejpřesnější formou hodnocení IAP je přímé laparoskopické měření pomocí intra-abdominálního katetru (Cresswell, 1993; Malbrain et al., 2006a). V klinické praxi se využívá pro pacienty s peritoneální dialýzou nebo kontinuální paracentézou. Pro vědecké účely je tato metoda zlatým standardem měření a hodnocení IAP. Transperitoneální monitoring však není v běžné klinické praxi ani v rehabilitačním výzkumu využíván z důvodu své invazivity (Malbrain, 2004; Malbrain et al., 2006a).

5.2.2. Intra-cavalní měření

Dalším příkladem přímého hodnocení IAP je intra-cavální měření. Katetr se zavádí skrz venu femoralis až do vena cava inferior pod ultrazvukovou nebo rentgenovou kontrolou. Tato metoda umožňuje přesné a kontinuální měření IAP. Je zde však riziko infekce, krvácení, a zároveň musíme počítat s časovou náročností a nutností speciálně vyškoleného zdravotnické personálu (Malbrain et al., 2013). Tato metoda je z výše uvedených důvodů velmi nevhodná pro monitoraci IAP v rámci posturálních funkcí.

5.2.3. Intra-vesicální měření

Intra-vesicální měření je nevyužívanější a nejspolehlivější metodou nepřímého měření IAP, a to především při vyšetření intra-abdominální hypertenze. Je tedy standardem při monitoraci intra-abdominálního kompartment syndromu. S výhodou se využívá u pacientů s již zavedeným intra-vesicálním katetrem. Tato metoda je založena na principu přenosu IAP na močový měchýř a jeho obsah. Měření se provádí v pozici v leže na zádech. Nevýhodou je riziko zanesení infekce do močového ústrojí či poranění uretry, proto tato metoda není ideální pro výzkum posturálních funkcí (Malbrain, 2004; Malbrain et al., 2013; Wise et al., 2017).

5.2.4. Intra-gastrické měření

Další možnost, jak měřit IAP nepřímo je pomocí nasogastrické či gastrostomické sondy, které jsou zavedeny do žaludku, a přináší vcelku přesnou metodu měření IAP (Grillner et al., 1978; W Hodges et al., 2005; Wauters et al., 2012). Pro pacienty je to metoda velmi subjektivně nepříjemná, proto se v rehabilitačních studiích rutinně nepoužívá. Jde také o metodu finančně nákladnější např. oproti intra-vesicálnímu měření. Další nevýhodou tohoto měření je ovlivnění IAP fyziologickými stahy žaludku (Sugrue et al., 1994). Naopak mezi výhody patří možnost kontinuálního snímání IAP, a to i během přirozených pohybů jako je chůze či běh (Grillner et al., 1978). V rehabilitaci se tato metoda využívá v rámci experimentů u pacientů s gastroesofageálním refluxem či s poruchami polykání, ale není typickou součástí běžného klinického vyšetření (Malbrain et al., 2006a).

5.2.5. Anorektální manometrie

Anorektální manometrie (high resolution anorectal manometry – HRAM), tedy měření IAP přes rektum, se provádí pomocí speciálního katetru nebo sondy. Tyto sondy jsou velice citlivé na změny tlaku, který snímají v reálném čase. Jsou velmi malé (průměr je 10 mm), tedy dobře tolerované pacienty, a téměř bez rizik jakéhokoliv poranění (Malbrain, 2004; Sugrue et al., 1994). Významnou výhodou je také možnost volného pohybu pacienta během celého měření. Proto je HRAM využívána v mnoha studiích zabývajících se změnami IAP v různých posturálních situacích (Kawabata et al., 2010; Sapsford et al., 2013).

Anorektální sonda je vybavena 12 senzory, z nichž každý měří tlak ve 12 po obvodu rozložených místech, díky čemuže tato metoda umožňuje snímat simultánně tlak ze 144 bodů. Tlak je snímán v mmHg a jeho hodnoty jsou následně konvertovány na elektrické signály a zpracovány počítačem (Pfeifer and Oliveira, 2006). Dva distálně položené senzory jsou uloženy za análními svěrači v oblasti ampulla rectum, kde měří intra-anální tlak. Zbývajících 10 sensorů snímá tlak vytvořený svěrači. Před začátkem měření se sonda kalibruje na nulový atmosférický tlak (Novak et al., 2021b).

HRAM je považována za nejbezpečnější a nejjednodušší metodu měření IAP (Malbrain, 2004; Malbrain et al., 2013). Měření intra-análního tlaku je spolehlivou metodou zjišťování IAP, i když není tak přesná jako např. intra-vesicální měření (Wise et al., 2017). Měření může komplikovat přítomnost reziduální stolice, špatná poloha zavedené sondy a stud pacienta (Bhatia and Bergman, 1986; Pfeifer and Oliveira, 2006). Kontraindikací měření je krvácení z dolního gastrointestinálního traktu či průjmovitá onemocnění (Kawabata et al., 2010). Nevýhodou je také vysoká pořizovací cena zařízení (Pfeifer and Oliveira, 2006).

Na podobném principu, jako je HRAM, pracuje intra-vaginální hodnocení IAP. Probíhá opět pomocí senzorů (i bezdrátových) a lze tak dobře hodnotit IAP při běžných denních aktivitách nebo při různých posturálních zátěžových situacích. Z logiky věci však tato varianta může být použita pouze u žen (Coleman et al., 2012; Shaw et al., 2014).

5.3. Měření aktivity trupových svalů

5.3.1. Elektromyografie

Běžnou metodou pro hodnocení aktivity svalů trupu je elektromyografie (EMG). Pro měření lze využít její povrchovou nebo jehlovou variantu. Nevýhoda tohoto měření je možnost hodnocení aktivity pouze několika konkrétních svalů, nikoliv globální trupové stabilizace a koordinace všech svalů trupu. Povrchovou EMG můžeme snímat pouze povrchové svaly, jehlová varianta, která by obsáhla svaly hlouběji uložené, je nepříjemná a invazivní metoda. Navíc je měření zatíženo vznikem mnoha artefaktů. EMG je proto využívána převážně ve výzkumu více, než v klinické praxi (De Luca et al., 2006; Henry and Westervelt, 2005; Junginger et al., 2010).

5.3.2. Ultrasonografie

Aktivita trupových svalů může být měřena také pomocí diagnostického ultrazvuku hodnocením šířky průřezu jednotlivých svalů. Ultrazvukem lze hodnotit i hluboko uložené svaly a zároveň je tato metoda nenákladná a neinvazivní. Přesnost měření a reliabilita je však závislá na zkušenostech a schopnostech vyšetřujícího (Hodges et al., 2003). Ultrazvukové vyšetření, stejně jako EMG, umožňuje objektivizaci aktivace jednotlivých valů, ale nikoliv globální trupové koordinace.

5.4. Měření expanze břišní stěny

Tenze břišní stěny je další projev aktivace trupových svalů a míry IAP, který je měřitelný. Tento neinvazivní přístup hodnotí vnější tlak, který produkuje expanze břišní stěny.

5.4.1. Ohmbelt senzor

Pro neinvazivní měření expanze břišní stěny v rámci testování posturální stabilizace trupu lze využít Ohmbelt (Nilus Medical LLC, 2019 c OHMBELT, Redwood City, CA, USA). Varianta, která byla vyvinuta pro vědecké účely obsahuje dva kapacitní senzory (průměr 15 mm, tloušťka 0,35 mm, maximální rozsah 0,45kg, minimální registrovatelná síla je 0,9g), které se upevní speciálními popruhy na trup. Komerční varianta, určená pouze pro biofeedback v rámci tréninku či terapie, obsahuje pouze jeden senzor. Kapacitní senzor (běžně využívaný v medicínském výzkumu (Ahmad and Barbosa, 2019; Salpavaara et al., 2008)) detekuje sílu, která je na něj aplikována. Senzory jsou v kontaktu se stěnou trupu a iniciální přítlak je nastaven mírou utažení popruhů, které senzory fixují. Senzory se umísťují podle potřeby na různé oblasti trupu, nejčastěji do oblasti TL a do oblasti nad tříselným vazem, kde je dobře přístupná břišní stěna a nejsou zde velká svalová bříška, jejichž kontrakce by mohla negativně ovlivnit měření.

Expanze břišní stěny během dechových a posturálních manévrů vyvíjí tlak na senzory a je snímaná jako síla v gramech za časovou jednotku (1 g =0,01N). Hodnoty jsou přenášeny do počítače, kde jsou graficky zobrazeny v reálném čase a automaticky uloženy pro další statistické zpracování. Senzory jsou vybaveny také akcelerometry, které detekují výchylky trupu během měření. Ohmbelt je vhodnou možností, jak neinvazivně hodnotit IAP skrze tenzi břišní stěny. Hodnotí celkovou trupovou stabilizaci a nejen lokální svalové aktivace. Výhodou je také skladnost přístroje, nízká pořizovací cena a jednoduchost samotného měření.

Při měření je nutné nejprve bez kontaktu s trupem nakalibrovat senzor na nulovou hodnotu a poté utáhnou pomocí popruhů na tělo probanda tlakem 110 g ± 10 g, což zajistí dostatečnou citlivost měření, ale zároveň nepředstavuje příliš velký tlak proti dechovým exkurzím trupu a není subjektivně nepříjemné pro měřeného probanda. Při dynamických testech je zde riziko posunu senzorů z TL a oblasti třísla, což může ovlivnit výsledky. Navíc u probandů s vyšším procentem podkožního břišního tuku může dojít z důvodu větší vzdálenosti mezi tlakovým senzorem a břišní svalovinou k ovlivnění měření. V komerční variantě, kdy využíváme pouze jeden senzor, nemáme informace z kontralaterální části trupu (Novak et al., 2021a).

5.4.2. Dynamic Neuromuscular Stabilization Brace (DNS Brace)

DNS je koncept zaměřující se na klinické hodnocení posturálně respiračních funkcí na základě poznatků z vývojové kineziologie. Přináší komplexní pohled se zaměřením na posturální stabilizaci, dechový vzor a dynamickou kloubní centraci. Zároveň nabízí funkční léčbu zejména muskuloskeletálních a neurologických obtíží (Casas et al., 2019; Kim et al., 2018; Kobesova et al., 2020, 2018, 2016, 2015; Mohammad Rahimi et al., 2019). Nicméně je důležité objektivně zhodnotit vyšetření a průběh terapie. Proto byl vyvinut přístroj DNS Brace, který neinvazivně a objektivně hodnotí expanzi břišní stěny a nepřímo tak měří míru IAP během posturálně respirační aktivity trupu (Chaitow et al., 2014; Terjung, 2011).

DNS Brace (vývoj: Ortotika, FN Motol V Úvalu 84, Praha) je plastová trupová ortéza vybavená čtyřmi elektricko – mechanickými sensory. Během vyšetření se na trup nasadí korzet, který naléhá pevně na kostěné trupové struktury, ale neomezuje expanze měkké břišní stěny. Sensory umožňují různé individuální nastavení a umísťují se bilaterálně do oblasti TLS a nad tříselný vaz. Silikonové koncové části mají polokruhovitý tvar a obsahují vzduchovou komoru, která se při zvýšeném tlaku břišní stěny deformuje a tato aktivita je registrována digitálním tlakovým senzorem umístěným na ortéze. Data jsou registrována v kPa a pomocí Bluetooth přenesena do mobilní aplikace, kde mohou být dále vyhodnocena.

DNS Brace může měřit volní, ale i reflexní odpověď posturální aktivaci trupu. Kromě výzkumných účelů může být ortéza využita pro objektivizaci vyšetření a terapie nebo jako biofeedback pro pacienta při nácviku správné trupové stabilizace. Výhodou oproti Ohmbelt je schopnost snímat expanzi trupu simultánně pomocí 4 senzorů čímž přístroj poskytuje komplexnější přehled o trupové stabilizaci. Samotné měření a získávání dat pomocí DNS Brace je relativně jednoduché, musí se ale dodržet základní pravidla. Senzory by měly být umístěny co nejpřesněji v oblasti nad tříselným vazem, aby neregistrovaly aktivaci svalových bříšek m. rectus abdominis pokud by byly příliš mediálně. V oblasti TL mohou nesprávně snímat tlak žeber nebo aktivaci extenzorů páteře. U obézních pacientů může být problém s příliš velkým obvodem trupu, což znemožňuje nasazení DNS Brace na trup pacienta. Je zde také velká vzdálenost mezi břišní dutinou a senzory z důvodu velkého množství podkožního tuku. Naopak u probandů s velmi úzkým pasem nemusí senzory být v dostatečném kontaktu se břišní stěnou, což negativně ovlivní výsledky. Limitem jsou posturální situace (dynamické pozice v leže, výrazná flexe nebo extenze trupu), kde může vlivem pohybu trupu dojít k posunutí DNS Brace, a tím k ovlivnění měření (Jacisko et al., 2020; Novak et al., 2021b).

5.4.3. Další přístupy

Podobný princip měření expanze břišní stěny použili i jiní autoři, např. Malátová et al., která hodnotila expanzi břišní stěny pomocí čtyři dynamometrů připevněných na trup. Ve studii popsala mechanismus, jak lze pomocí dynamometrů měřit aktivitu trupové stabilizace. Všechny svaly trupu musí fungovat jako jedna funkční jednotka, aby se výsledek projevil ve zvýšení IAP, který ovlivní tenzi břišní stěny. Autoři také objektivizovali efekt šestitýdenní terapie zaměřené právě na aktivitu stabilizačního systému páteře (Malátová et al., 2013, 2008; Malátová and Dřevikovská, 2009).

Analogicky k měření přistoupil ve své studii van Ramshorst et al., který koreloval tenzi břišní stěny a vzestup IAP. V této studii byly použity speciální dynamometry k měření tuhosti břišní stěny na kadaverech poté, co insuflací zvyšovali tlak břišní dutiny. Studie potvrdila, že za laboratorních podmínek (studie neměřila živé probandy) tenze břišní stěny reflektuje změny IAP (van Ramshorst et al., 2011).

Korelaci mezi měřením tuhosti břišní stěny snímané tenzometrem a IAP měřeným pomocí tlaku v močovém měchýři během dechového cyklu u živých probandů potvrdil i Chen et al. (Chen et al., 2015). Tito autoři zároveň prokázali, že body mass index nemá vliv na korelaci mezi tenzí břišní stěny a IAP. Pro hodnocení aktivity zejména m. TA byl dalším týmem autorů použit přístroj Pressure biofeedback unit, který seskládá ze tří tlakových sond (vzduchem naplněných vaků). Pro měření tímto přístrojem je možné využít pouze pozice v leže. Tlakové sondy se vloží pod lumbální část páteře. Pacient je poté vyzván, aby pomocí aktivity trupových svalů udržel tuto část páteře v kontaktu s podložkou a tím vytvořil požadovaný tlak na sondy. Pacienti mohou podobným postupem v leže na břiše vytvářet tlak na sondy umístěné tentokrát v oblasti nad tříselným vazem (Lima et al., 2012). Obdobně měřil aktivitu svalů trupu i Kumar et al. kdy umístil tlakové sondy pod ležícího pacienta v oblasti třísla a zvýšením nitrobřišního tlaku docházelo i ke zvýšení tlaku břišní stěny na sondu. (Kumar et al., 2012). Limitem u těchto přístupů může být fakt, že k přítlaku břišní stěny k na senzor mohlo dojít i pomocí pohybu pánve (substitucí svalů například dolních končetin) a ne pouze zvýšením IAP.

6. Výzkum

Následující část práce prezentuje publikované výsledky šesti vědeckých prací autora, které se vztahují k tématu disertační práce, tj. objektivní hodnocení posturální funkce břišních svalů a nitrobřišního tlaku.

6.1. Postural and respiratory function of the abdominal muscles: A pilot study to measure abdominal wall activity using belt sensors

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Postural and respiratory function of the abdominal muscles: A pilot study to measure abdominal wall activity using belt sensors

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Abstract.
BACKGROUND: The abdominal muscles play an important respiratory and stabilization role, and in coordination with other muscles regulate intra-abdominal pressure (IAP) to stabilize the spine.
OBJECTIVE: To examine a new, non-invasive method to measure activation of the abdominal wall and compare changes in muscle activation during respiration while breathing under a load, and during instructed breathing.
METHODS: Thirty-five healthy individuals completed this observational crossover study. Two capacitive force sensors registered the abdominal wall force during resting breathing stereotype, instructed breathing stereotype and under a load.
RESULTS: Mean abdominal wall force increased significantly on both sensors when holding the load compared to resting breathing (Upper Sensor: $P < 0.0005$, $d = -0.46$, Lower Sensor: $P < 0.0005$, $d = -0.56$). The pressure on both sensors also significantly increased during instructed breathing compared to resting breathing (US: $P < 0.0005$, $d = -0.76$, LS: $P < 0.0005$, $d = -0.78$).
CONCLUSIONS: The use of capacitive force-sensors represent a new, non-invasive method to measure abdominal wall activity. Clinically, belts with capacitive force sensors can be used as a feedback tool to train abdominal wall activation.

Keywords: Spinal stabilization, respiration stereotype, intra-abdominal pressure (IAP), capacitive force sensors

1. Introduction

Over the past two decades, numerous authors have investigated lumbar spine stabilization [1,2], motor control of the trunk muscles [3,4], and the regulation of intra-abdominal pressure [5,6]. Balanced coordination between the diaphragm, pelvic floor muscles, and abdominal wall musculature is critical for IAP regulation which forms an important spinal stabilization mechanism [7–9]. The pelvis and lumbar spine are reflexively stabilized before the limb movements start [10–12]. This feed forward stabilization mechanism is secured by the trunk muscles. The diaphragm works in conjunction with the pelvic floor and deep intrinsic muscles of the spine and the transversus abdominis to create stiffness and minimize other intrinsic and extrinsic stressors to the spine during motion [13]. Biomechanical studies confirm that pressurization of the abdomen increases lumbar spinal stability, but the degree of spinal stability is not substantially influenced by selective activation of certain abdominal muscles [7]. Forced activity of transversus or obliques may cause reductions in the ac-

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tivation of other abdominal muscles and even produce decreased lumbar stability [7].

Appropriate functional tone and conditioning the abdominal wall to work as one harmonic unit with the pelvic floor musculature is a critical stabilization component that optimizes the "push back" of the viscera up into the diaphragm, helping expansion of the lower rib cage for respiration [13]. According to Wallden a deconditioned or inhibited abdominal wall causes visceroptosis, reducing the pressure the viscera exerts into the diaphragm to open the lower rib cage for inhalation, and driving the diaphragm back upward during full exhalation [13]. The postural-respiratory function of the trunk muscles is inseparable. With heavy load lifting, trunk muscle activation in the abdominal and thoracic cavities act like a rigged-walled cylinder, providing increased spinal stability [14]. The regulation of IAP within the abdominal wall in coordination with diaphragm and pelvic floor muscles significantly contributes to spinal stabilization and protects the spine during loading [15,16]. Perhaps not only the amount of the abdominal wall activation but also the type of contraction, i.e. eccentric vs. concentric plays a role in spinal stabilization. With postural activites, the diaphragm descends caudally to pressurize intra-abdominal contents [17]. The pelvic floor must support the viscera from bellow. Since the viscera are non-compressible, one can assume that the abdominal wall must react to diaphragmatic descend by eccentric contraction. Insufficient distension or exccesive initial concentric contraction of the abdominals preventing diaphragmatic descend during postural activites may compromise the whole stabilization mechanism. Poor coordination of postural muscles and insufficient stabilizing function of deep back muscles, diaphragm, abdominal and pelvic floor muscles may result in spinal disorders associated with back pain, such as deformation spondyloarthrosis, intervertebral disc protrusion or spondylolisthesis [18,19].

Various measurement procedures have been used to investigate the postural-respiratory function of the abdominal muscles and related IAP changes. Esohpageal, gastric [20], intravesical [21], anal [22,23], and vaginal [24] probes can measure IAP, yet these methods are often time consuming and uncomfortable for patients. Electromyography [23] and ultrasound [25] assessments have also been used to analyze activity of the abdominal muscles, but these methods can be burdensome, technically demanding to perform while the former poses serious difficulty regarding its reproducibility and hence interpretation.

Table 1
Descriptive statistics of the sample

	Age (years)	Height (cm)	Weight (kg)	BMI
Mean	21.26	170.51	63.17	24.07
SD	1.62	6.49	7.94	3.02
Min	19	160	47	17.27
Max	25	185	80	27.62

This paper presents a new, non-invasive method to measure force of the abdominal wall using capacitive force sensors, which may help medical practicioners provide quick, visual information to patients regarding their postural-respiratory function.

Therefore, the purpose of this research was to compare how activation of abdominal muscles changes during respiration while breathing under a load and when being instructed to modify breathing stereotype in a healthy population.

2. Methods

2.1. Participants

This study included 35 healthy individuals, 8 males and 27 females, aged 19–25 years. Table 1 shows descriptive statistics of the sample. The participants have not experienced acute or chronic musculoskeletal pain, reported no pain during the measurements, never suffered from any serious trunk pathologies, never undergone any trunk operations and have never received any therapy or training focusing on intra-abdominal pressure activation or abdominal wall expansion. Individuals with body mass index (BMI) over 30 were excluded from the study. Written informed consent was obtained from each participant, and this study was approved by an Institutional Ethics Committee (Ethics Committee of the University Hospital Motol and 2nd Faculty of Medicine, Charles University in Prague. No. 1263.1.15/19; approval date: November 6, 2019). The study conforms with The Code of Ethics of the World Medical Association.

2.2. Instruments

For the noninvasive examination of abdominal muscles function, a unique device called Ohm Belt (Nilus Medical LLC, 2019 © OHMBELT, Redwood City, CA, USA). A research version of the device was designed by the manufacturer for the trial purposes, which differs from the commercial version in that two sensors recorded data simultaneously with a software app to

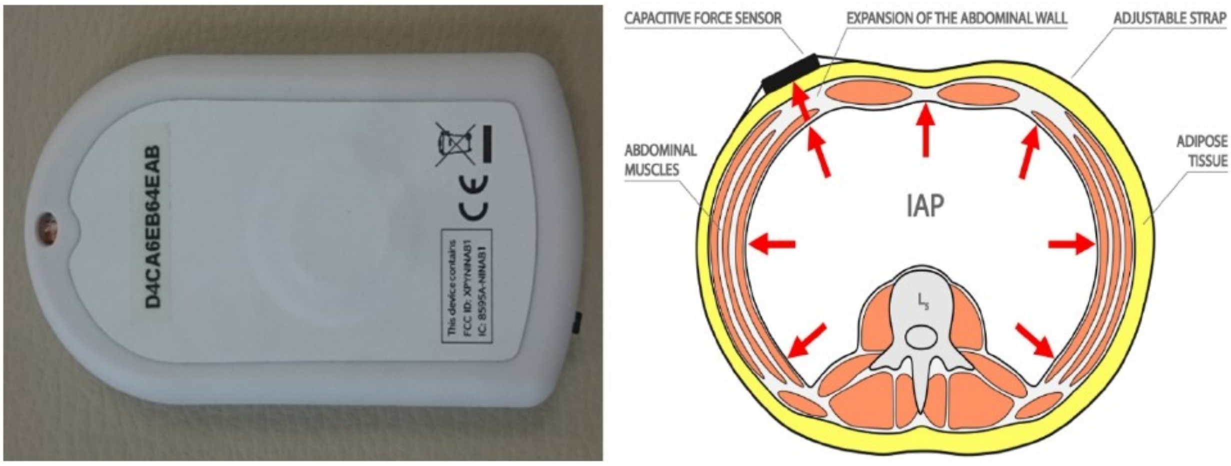

Fig. 1. Close-up picture of the capacitive force sensor and a scheme of abdominal cavity with expansion of the abdominal wall and attached sensor.

display and record both sensor force data. It consists of two capacitive force sensors of 15 mm diameter, 0.35 mm thickness, full scale range 0.45 kg, minimal detectable force 0.9 g (Fig. 1), attached to the abdominal wall by adjustable straps. The device utilizes force-sensing capacitor type of sensor, which consists of a material whose capacitance changes when a force is applied. Such sensors are also known as "force-sensitive capacitors" and reported to be used in other medical research projects [26–28]. This sensor is an example of parallel plate capacitator (see Fig. 1). For small deflections, there is a linear relationship between applied force and change in capacitance. Force sensor, facing the subject's skin, is pressed against the abdominal wall by the adjustable firm strap (see Fig. 1). Abdominal wall expansion and retraction is recorded by the sensor as a force (The "abdominal wall force"). The sensors register the force exerted by the abdominal wall during respiration and various postural tasks. The abdominal wall force is measured in grams over a period of time, where $1\text{ g} = 0.01\text{ N}$. The gram scale was selected to provide users with feedback in integer rather than decimal values. Abdominal wall force was measured by the sensor and recorded in grams over a period of time. The force displayed on the graph scale in grams is, therefore, technically in the gram-force unit (gf). The dual-channel pressure sensor consists of two sensors which monitor simultaneously the instantaneous muscle force at two different locations. Both the amount of the force and its dynamics over time can be analyzed. The sensors are also equipped with accelerometers to capture any kyphotic trunk synkinesis, i.e. substitutive trunk movement replacing abdominal muscle activation. A built-in tensometric transducer converts the force to the digital signal that is transmitted wirelessly via bluetooth to the computer where the software graphically displays the results. The program records any time sequences with the numerical values being automatically exported into MS Excel. Immediate data analysis, graphical imaging and data saving is available.

2.3. Assessments

The assessments of all participants were performed under the same conditions (daytime, assessment room, temperature), and by the same examiner. Each participant was in an upright seated position, with hips and knees flexed at 90°, and both feet supported on the floor (Fig. 2). First, a pilot study was performed on 20 healthy individuals to measure abdominal wall activity in various postural and breathing situations, using different ways of fixation and placement of the sensors to achieve maximal measurement accuracy and sensitivity. By repeated measurements, it was determined that fixation with firm but flexible belts under the pressure of of 120 grams $\pm$ 10 g for the upper sensor (US) and 140 grams $\pm$ 10 g for the lower sensor (LS) allows for sufficiently accurate measurements while not limiting trunk and abdominal wall movements. Before each measurement, boths sensors were calibrated to a baseline of zero and positioned on each participant using palpation by a skilled manual therapist. The US was placed on the superior trigonum lumbale, bellow the floating ribs, and the LS was placed above the groin at the intersection of the mammilar and bispinal connecting line. Sensors were randomly placed on the left or right side of the body. The sensors were fixed during tidal expirium.

The participants were instructed to maintain the upright sitting position throughout the course of the whole

Fig. 2. Resting breathing assessment. Force sensors are placed under the belts.

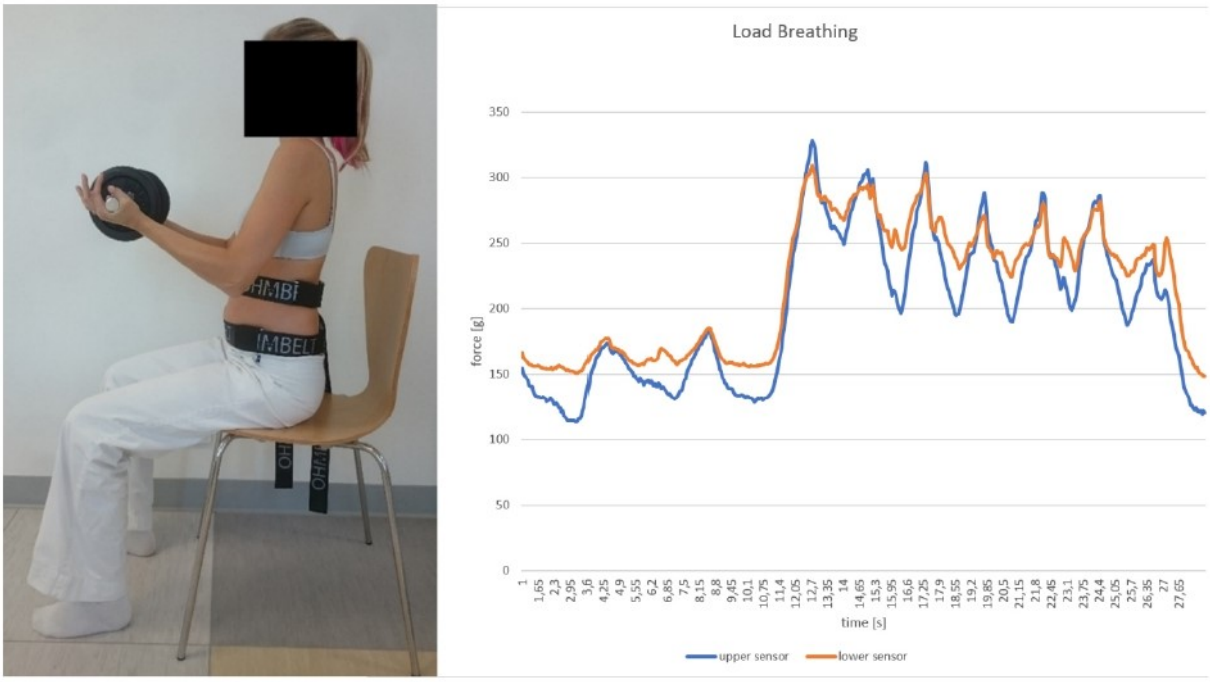

Fig. 3. Load breathing assessment. At the 10th second the weight was put into participant's hands (note the steep increase of both lines in the graph).

assessment, avoiding increased spinal kyphosis or lordosis. In all individuals, the abdominal wall activity was recorded for a total period of 15–20 seconds for each scenario. Abdominal activity fluctuated when each participant began to hold the load, and upon releasing the load, so only 10-second intervals of stable activation

Fig. 4. Instructed breathing assessment. First, the individual breathes normally, then at the 10th second he/she was instructed to direct the breath towards both sensors (steep increase of both lines in the graph).

were used for the mean statistical analysis calculated separately for each sensor. First, the natural stereotype of resting breathing (RB) was monitored (scenario 1, Fig. 2). Then, the participants were breathing naturally when sitting upright and holding a load corresponding to 20% of their body weight with elbows flexed at 90°. This was scenario 2, i.e. load breathing (LB), (Fig. 3). And finally, instructed breathing (IB) was monitored (Fig. 4). The participants were instructed to voluntarily and maximally expand their abdominal wall, directing inspiration towards the sensors and maintaining maximum pressure contact with the sensors during expiration.

2.4. Statistical analysis

Descriptive statistics were calculated for each measure. Paired-samples t tests were used to compare abdominal wall pressure in both sensors during resting breathing with the interventions, and also to compare inter-sensor differences between measurements during each condition. Cohen's d effect sizes were calculated for the differences between breathing conditions as the difference between groups divided by the pooled standard deviation. Effect sizes were interpreted as very small (< 0.2), small (0.2–0.5), medium (0.5–0.8), or large (> 0.8). Power analysis, using G*Power 3.1, indicated an 80% chance of detecting a medium effect size of 0.5 in 34 subjects with statistical significance determined *a priori* at $p < 0.05$ (two-tailed). Data analyses were conducted using the Statistical Package for the Social Sciences (SPSS version 26.0 for Mac; IMB Corp, Armonk, NY).

3. Results

Thirty-five participants completed the study. Table 2 presents the amount of force of the abdominal wall (g) during resting breathing, loaded breathing and instructed breathing ($n = 35$) for both sensors. The paired sample t-test indicated that the mean abdominal wall force increased significantly on both sensors when holding the load compared to the resting breathing (P for both sensors < 0.0005). The force on both sensors also significantly increased during instructed breathing compared to the resting breathing (P for both sensors $<$ 0.0005). Figure 5 depicts the results.

The inter-sensor difference was also compared for all three measured scenarios (resting, under load, and

Table 2
External force changes of the abdominal wall (g) during loaded breathing and instructed breathing ($n = 35$)

Measure	Breathing intervention	Resting mean (SD)	10 second mean (SD)	Mean difference (SD)	95% CI of difference	Effect size	P Value
Upper sensor	Loaded	123.75 (21.95)**	165.07 (39.44)**	−41.32 (38.00)	(−54.38, −28.27)	−0.46	< 0.0005*
	Instructed		228.31 (64.96)	−104.56 (60.64)	(−125.39, −83.73)	−0.76	< 0.0005*
Lower sensor	Loaded	141.98 (18.19)**	191.74 (40.51)**	−49.76 (39.79)	(63.43, −36.09)	−0.56	< 0.0005*
	Instructed		249.02 (66.09)	−107.04 (63.79)	(−128.95, −85.13)	−0.78	< 0.0005*

*Statistical difference observed between conditions ($P < 0.05$). **Statistical difference observed between sensors ($P < 0.05$). Note: Values are (g). Effect size = calculated Cohen's d.

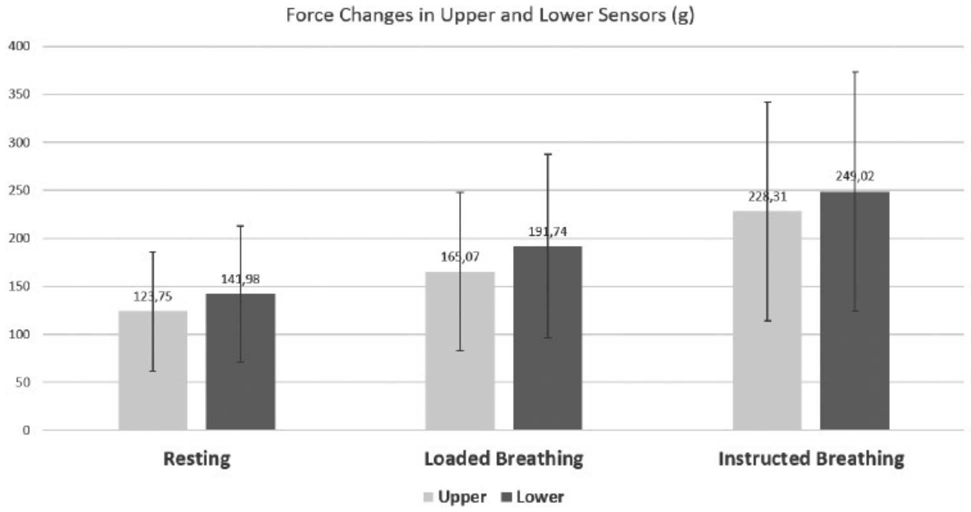

Fig. 5. Statistical comparison of forces on both sensors at resting, loaded, and instructed breathing.

instructed breathing). There was a significantly greater force on the lower sensor in the resting condition ($p < 0.0005$), and in the loaded condition ($p = 0.001$), but not in the instructed breathing condition ($p = 0.068$). Figure 5 depicts the inter-sensor difference.

4. Discussion

This study presents a new method to analyze activity of the abdominal wall using capacitive force sensors. Originally, the sensors were produced by a medical technology developer to offer feedback to LBP clients training optimal breathing stereotype. Research suggests patients with low back pain (LBP) often demonstrate sub-optimal respiratory parameters [29,30] and confirms a positive effect of breathing exercises on LBP [31,32]. Clinically, insufficient activation of the latero-dorsal sections of the abdominal wall (i.e. in superior trigonum lumbale and over the lower abdominal wall just above the groin) are common findings in LBP patients [33,34]. Therefore, the sensors were placed in these locations because they are usually the most difficult to voluntarily activate in an eccentric manner. Also, a similar placement of abdominal wall pressure measuring device was previously used in studies published by other authors [35,36]. Synergy between the diaphragm, pelvic floor, abdominal wall and spinal extensors is necessary to stabilize the spine. During stabilization, the concentric activity of the diaphragm is followed by the eccentric activity of the entire abdominal wall. This synergy increases intra-abdominal pressure (IAP) that stabilizes the lumbar spine anteriorly, balancing with the spinal extensors that secure stabilization posteriorly [37]. Based on existing literature [6,38,39], we assume the pressure monitored by the sensors is not only activity exerted by the abdominal muscles but mainly the IAP resulting from the complex coordination of all core stabilizers.

This study confirms that pressure exerted by the abdominal wall increases with increased postural load, because the activity measured on both sensors during LB was significantly higher comparing to RB. This further supports electromyography (EMG) studies reporting increased abdominal muscle activity during posturally challenging situations [40] and when lifting the load [41], as well as studies confirming IAP elevation during postural tasks and load lifting [9,37]. Within-limb movements, and coactivation of the diaphragm with abdominal muscles cause an increase in IAP [37]. This is a very important stabilizing mechanism because IAP elevation increases stiffness of the lumbar spine [9,42]. Applying simple and non-invasive capacitive force sensors, we obtained similar results reported by other complicated and sophistic methods such as multichannel EMG analysis or IAP gastric, esophageal or intra-annal pressure measurements [23,25]. Furthermore, we statistically confirmed that healthy, young individuals are able to voluntarily activate the coordination between the diaphragm, abdominal muscles and pelvic floor muscles, because the force on both sensors significantly increased during IB comparing to RB. This again, supports other studies showing how breath control and abdominal muscle control influences IAP [23,43]. We purposefully performed the IB test at the end of the assessment to exclude any learning process. First resting and loaded breathing spontaneous uncorrected stereotypes were analyzed and only then were instructions given on how to breath. The individuals were cued to direct the breath towards both sensors. The goal was to measure the amount of voluntary pressure exerted on sensors during maximum inhalation directed to the sensors. The second goal was to confirm it is actually possible to teach participants how to voluntarily activate the abdominal wall sections under the sensors. This may be of potential benefit in the treatment and training of LBP individuals who frequently demonstrate an inability to activate such areas of the abdominal wall both during breathing and postural tasks [33,34]. Further studies are needed to confirm.

Interestingly, this study showed that postural activation when holding a load corresponding to 20% body weight (LB scenario) requires, on average, about two-thirds of the maximum muscle coactivation generated by the conscious maximum force of the abdominal wall against the sensors (IB scenario). Similarly, Essendrop et al. reported IAP increased from 0 to 40% when holding a load of 15% body weight [42]. However, it remains questionable what amount of activation would occur when holding a heavier gload, which is common during activities of daily living or sport.

A similar measurement of the abdominal wall expansion was done by Malatova et al. using an electromechanical dynamometer [44–46]. The authors describe how muscular dynamometers can be used to evaluate activation of the whole deep stabilizing spine system (DSSS) because abdominal muscles comprise the DSSS, arguing that the DSSS works as one functional unit and dysfunction of just one DSSS muscle is related to total dysfunction of the whole muscle system [44]. Malatova also used the dynamometer to analyze the effect of a six-week intervention program focusing on optimal body posture and DSSS training [46]. Comparing to Malatova's rather big muscular dynamometer, these sensors are smaller in size and transmit signals to a PC via Bluetooth, allowing practicioners to analyze more dynamic situations including all types of exercises. Also, unlike Malatova's measuring device, the sensors used in this study are commercially available (Nilus Medical LLC, 2019 © OHMBELT).

In a study on 45 asymptomatic women, Malatova identified more excessive activation of the upper sections of the abdominal wall compared to lower sections, questioning if this is a natural or pathological stereotype [44]. Our study demonstrated significantly greater pressure on the lower sensor in the RB condition ($p < 0.0005$), and in the LB condition ($p = 0.001$), for the IB condition the activity on the lower sensor was also greater but not statistically significant ($p = 0.068$). This topic deserves more research attention. It is necessary to determine how much difference can be considered physiological and what is already abnormal. Postural responses of the abdominal muscles differ between body positions, the recruitment and contribution of abdominal muscle regions to stabilize the trunk varies, and regional differentiation in abdominal muscle activity may be a natural stabilization mechanism [47].

It has been shown that selective activation of the individual abdominal muscles does not significantly increase spinal stability [7]. Spinal stabilization training should therefore focus on global coordination of all muscles involved in stabilization function and IAP regulation rather then addressing individual abdominal muscles. Abdominal wall pressure changes were previously monitored by other authors [35,36] reporting inverse significant correlations between ability to activate the abdominal wall and pain severity in LBP population [36]. Esophageal, gastric, anal or vaginal sensory measuring IAP [9,48] as well as EMG [3,48] or ultrasound [49] examination procedures help to analyze activity of the abdominal wall muscles. These techniques inform us about muscle activity but do not distinguish eccentric from concentric types of contraction and as a result do not provide information about an individual's ability to expand their abdominal wall. Abdominal wall expansion can be assessed clinically by palpation [33,34], but clinical abdominal assessment showed poor sensitivity and accuracy for IAP pressure changes [50]. Trunk and abdominal circumference measurements can be highly influenced by the adipose tissues, therefore may also be unreliable [51]. The proposed method using capacitive force sensors may become a new, simple and non-invasive method to measure abdominal wall force. Future studies are needed to determine its sensitivity, accuracy and correlation with direct IAP measurements.

This study has some limitations. Based on available research [6,38,39] we assume the detected amount of abdominal wall force is related to IAP changes, but IAP was not directly measured in this study. Future research correlating IAP with abdominal wall force would be useful in strengthening the findings of this study. This method of IAP detection may lose sensitivity in very obese individuals. The exact placement of the sensors would be less consistent due to difficult palpation of the anatomical landmarks, and the pressure measurement accuracy limited by a sick adipose tissue. Obese clients with BMI > 30 were excluded. Additionally, the sensor's fixation may alter the measurements. Too loose fixation of the belts reduces the sensitivity of the sensors, whereas too tight of fixation limits the ability to expand the abdominal wall, compromising the measured function. Placement of each sensor was unilaterally randomized, however in future studies we plan to use four sensors placed on both sides of the trunk to distinguish bilateral differences. Finally, this pilot study was performed on asymptomatic individuals, which does not mean all measured subjects performed with optimal muscular co-activation. In future studies, a larger number of individuals should be involved, comparing asymptomatic subjects with those suffering from LBP or other types of musculoskeletal problems.

5. Conclusions

This study presenst a new non-invasive method to measure abdominal wall force using belts with capacitive force sensors. The activity of the abdominal wall muscles significantly increases when lifting a load and with a purposeful activation during instructed breathing stereotype comparing to resting breathing. Future studies need to confirm if abdominal wall activation measured by the sensors correlates with direct IAP measurements.

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Author contributions

CONCEPTION: Jakub Novak, Pavel Kolar and Alena Kobesova.
PERFORMANCE OF WORK: Jakub Novak.
INTERPRETATION OR ANALYSIS OF DATA: Jakub Novak and Andrew Busch.
PREPARATION OF THE MANUSCRIPT: Jakub Novak, Andrew Busch and Alena Kobesova.
SUPERVISION: Alena Kobesova.

Ethical considerations

Written informed consent was obtained from each participant, and this study was approved by the Ethics Committee of the University Hospital Motol and 2nd Faculty of Medicine, Charles University in Prague. No. 1263.1.15/19; approval date: November 6, 2019. The study conforms with The Code of Ethics of the World Medical Association.

Conflict of interest

There are no conflicts of interest to disclose.

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6.2. Intra-abdominal pressure correlates with abdominal wall tension during clinical evaluation tests

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Original Articles

Intra-abdominal pressure correlates with abdominal wall tension during clinical evaluation tests

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ABSTRACT

Background: The abdominal muscles play an important respiratory and stabilization role, and in coordination with other muscles regulate the intra-abdominal pressure stabilizing the spine. The evaluation of postural trunk muscle function is critical in clinical assessments of patients with musculoskeletal pain and dysfunction. This study evaluates the relationship between intra-abdominal pressure measured as anorectal pressure with objective abdominal wall tension recorded by mechanical-pneumatic-electronic sensors.

Methods: In a cross-sectional observational study, thirty-one asymptomatic participants (mean age = 26.77 ± 3.01 years) underwent testing to measure intra-abdominal pressure via anorectal manometry, along with abdominal wall tension measured by sensors attached to a trunk brace (DNS Brace). They were evaluated in five different standing postural-respiratory situations: resting breathing, Valsalva maneuver, Müller's maneuver, instructed breathing, loaded breathing when holding a dumbbell.

Findings: Strong correlations were demonstrated between anorectal manometry and DNS Brace measurements in all scenarios; and DNS Brace values significantly predicted intra-abdominal pressure values for all scenarios: resting breathing ($r = 0.735$, $r^2 = 0.541$, $p < 0.001$), Valsalva maneuver ($r = 0.836$, $r^2 = 0.699$, $p < 0.001$), Müller's maneuver ($r = 0.651$, $r^2 = 0.423$, $p < 0.001$), instructed breathing ($r = 0.708$, $r^2 = 0.501$, $p < 0.001$), and loaded breathing ($r = 0.921$, $r^2 = 0.848$, $p < 0.001$).

Interpretation: Intra-abdominal pressure is strongly correlated with, and predicted by abdominal wall tension monitored above the inguinal ligament and in the area of superior trigonum lumbale. This study demonstrates that intra-abdominal pressure can be evaluated indirectly by monitoring the abdominal wall tension.

1. Introduction

Spinal stability is secured by the bone structures, ligaments, and via coordinated activation between spinal extensors and flexors and all muscles regulating the intra-abdominal pressure (IAP) (Cholewicki and McGill, 1996; Hodges et al., 2005). The diaphragm and pelvic floor form two pistons which push against each other increasing the pressure in the abdominal cavity. Contraction of the abdominal muscles resists lateral movement of the contents within the abdominal cavity (Chaitow et al., 2014; Hodges, 1999). IAP is essentially a hydraulic pressure effective in all directions, stabilizing the torso and reducing axillary compression during activities that increase the demands on spinal stabilization, such as lifting heavy loads (Cobb et al., 2005; Grillner et al., 1978). Hodges et al. has confirmed that an increase in IAP alone without activity of abdominal or back muscles still enhances the stability of the lumbar spine (Hodges et al., 2005).

The amount of IAP can be measured by several different invasive and non-invasive methods. The most accurate is direct laparoscopic measurement using an intra-abdominal catheter (Malbrain et al., 2006). Indirect urethral measurement is considered to be the most frequent and reliable method to monitor IAP; however, this can result in urinary tract infections or urethral injury, therefore, it is not often used in postural function research (Malbrain et al., 2013; Wise et al., 2017).

In rehabilitation medicine, instrumental IAP measurement via rectal

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or gastric probes are mainly used in experimental studies, and are not typically used in routine clinical assessment (Malbrain et al., 2006). Gastric or nasogastric tubes inserted into the stomach provide quite accurate IAP measurements, however, it is quite uncomfortable for patients and an expensive method requiring highly trained personnel (Grillner et al., 1978; Hodges et al., 2005; Wauters et al., 2012). Special catheters or probes inserted into the rectum are used for anorectal measurements. Such pressure sensitive devices convert mechanical signals into electrical signals recorded and displayed on a computer monitor (Pfeifer and Oliveira, 2006). Recently, thin electric probes have become available. Smaller devices lead to fewer artifacts thus offering more exact display and measurement. Small probes are easy to install, temperature resistant, very sensitive to pressure changes and well tolerated by patients, with infrequent side effects (Malbrain et al., 2006; Sugrue et al., 2015). The disadvantage is the high purchase price (Pfeifer and Oliveira, 2006). Such IAP recording has been reported in many studies exploring IAP changes in various postural situations (Kawabata et al., 2010; Sapsford et al., 2013).

IAP measurement has also been combined with simultaneous electromyography or ultrasound assessments of core muscles. However, these methods do not evaluate the global coordination of the trunk muscles but rather local muscle activation. In addition, significant inaccuracies during such recording have been reported (Henry and Westervelt, 2005; Junginger et al., 2010).

In clinical practice, palpation of the abdominal wall tension (AWT), especially in the area above the inguinal ligament and in the upper trigonum lumbale is used to evaluate an individual's ability to regulate their IAP (Kobesova et al., 2020). Available studies suggest that the AWT occurs as a result of increased IAP (Cresswell, 1993; Kumar et al., 2012; Tayebi et al., 2021; van Ramshorst et al., 2011). Different types of sensors have been used to measure the AWT during various postural tasks related to IAP changes (Chen et al., 2015; Malátová et al., 2013, 2008; Novak et al., 2020; van Ramshorst et al., 2011). This study presents simultaneous recording of IAP measured as anorectal pressure and AWT measured via four sensors attached to a trunk brace. In an attempt to further understand the relationship between IAP and outward tension of the abdominal wall, the purpose of this research was to compare anorectal manometry measurements, largely considered the gold standard in ambulatory patients, with abdominal wall outward tension measured by a trunk brace during clinical assessments.

2. Methods

2.1. Participants

Thirty-one asymptomatic volunteers were recruited for the study. Written informed consent was obtained from each participant, and demographic characteristics of the sample including age, weight, height and BMI are shown in Table 1. Exclusion criteria were any symptomatic neurologic, orthopedic, respiratory, internal or musculoskeletal disorder, spine or abdominal surgery, severe trauma during the last year, pregnancy, and history of therapy focusing on IAP training. The study conforms with The Code of Ethics of the World Medical Association and was approved by an Institutional Ethics Committee (Ethics Committee of the University Hospital Motol and 2nd Faculty of Medicine, Charles University in Prague. No.1263.1.15/19; approval date: November 6, 2019). This study adhered to the Helsinki declaration.

Table 1
Participant's anthropometric characteristics. $N = 31$, 15 males, 16 females.

	Age (years)	Height (cm)	Weight (kg)	BMI
Mean	21.3	170.5	63.2	24.1
SD	1.6	6.5	7.9	3
Min	19	160	47	17.3
Max	25	185	80	27.6

2.2. DNS Brace

To monitor AWT, a special new device called DNS Brace was used (Fig. 1 – A,C). The DNS abbreviation is derived from the rehabilitation concept called Dynamic Neuromuscular Stabilization (DNS) (Kobesova et al., 2019, 2016). DNS emphasizes the importance of IAP in spinal stabilization and treatment. The diaphragm, pelvic floor and abdominal wall muscles regulate the IAP (Hodges et al., 2007). IAP increases during postural activity (Hodges and Gandevia, 2000), resulting in a contraction and expansion of the abdominal wall due to muscle activity. Abdominal wall expansion and contraction result in pressure that compresses the DNS Brace sensors. The Brace is an original device produced by Ortotika, FN Motol V Úvalu 84, Praha. Four mechanical-pneumatic-electronic sensors are placed on the inner wall of plastic trunk orthosis. Two ventral sensors are located bilaterally above the groin and two sensors are located on the brace parts adhering to latero-dorsal sections of the abdominal wall (trigonum lumbale superius). Silicon brace sensors contain the inner air-chamber that is deformed by the abdominal wall pressure. The values recorded in kilopascals (kPa) are transferred via Bluetooth, stored and graphically displayed in a smart-phone device. More details about the brace can be found elsewhere (Jacisko et al., 2020). The brace sensors measure the pressure exerted by the abdominal wall in kilopascals (kPa) (Figs. 2. B, 3. B, 4. B) and transfer the data via Bluetooth to a smart-phone or computer so the data can be statistically processed and graphically displayed.

2.3. High resolution anorectal manometry

The intra-abdominal pressure was measured using the ManoScan™ AR HRM system (Given imaging, 15 Hampshire Street, Mansfield, MA 02048 US). It allows for complex assessment of anorectal pressures (Fig. 1 – B,C). The anorectal probe is equipped with 12 channels each measuring 12 circumferentially located spots thus recording pressures from 144 points simultaneously. The diameter of the probe is 10 mm. The pressure values are measured in mmHg (Figs. 2. A, 3. A, 4. A) and transferred at 0.1 s intervals to a computer, where the data can be further processed. The ManoView™ software color-visualizes the measured pressures. Two distal sensors located behind the anal sphincters in the ampulla of rectum monitor the IAP. The remaining 10 probe sensors record the pressures produced by the sphincters. Before starting the measurement, the probe must always be calibrated to 0 atmospheric pressure and a ManoShield rubber protection must be fitted. The probe records pressure in real time.

2.4. Assessments

The assessment of all participants was performed by the same examiners under similar conditions (time of day, assessment room, temperature). All participants were first informed about the procedure in detail. After calibration, the anorectal probe was inserted into the participant's anus in a side lying position. Then, the participant stood up and the correct location of the probe was ensured. By activating the sphincters, it was verified that the 2 distal sensors are located in the rectal ampulla monitoring the IAP but not the activity of the sphincters (McCarthy, 1982; Pfeifer and Oliveira, 2006; Shafik et al., 1997). Then, DNS Brace was fixed to the participant's trunk and the sensors were calibrated to 0 kPa during the tidal exhalation prior to each measurement. The dorsal sensors were adjusted to be placed bilaterally in the superior trigonum lumbale, bellow the floating ribs, and the ventral sensors were placed bilaterally above the groin at the intersection of the mammilar and bispinal connecting line. Then, the participants were instructed to maintain the upright standing position throughout the whole measurement, avoiding increased spinal kyphosis, lordosis or extremity movements. Five postural tests were performed by each subject and evaluated by DNS Brace and Anorectal manometry simultaneously in the same order. The anorectal pressure and AWT values were

Fig. 1. A: DNS Brace, B: Anorectal probe, C: Participant equipped with DNS Brace and anorectal probe during assessment.

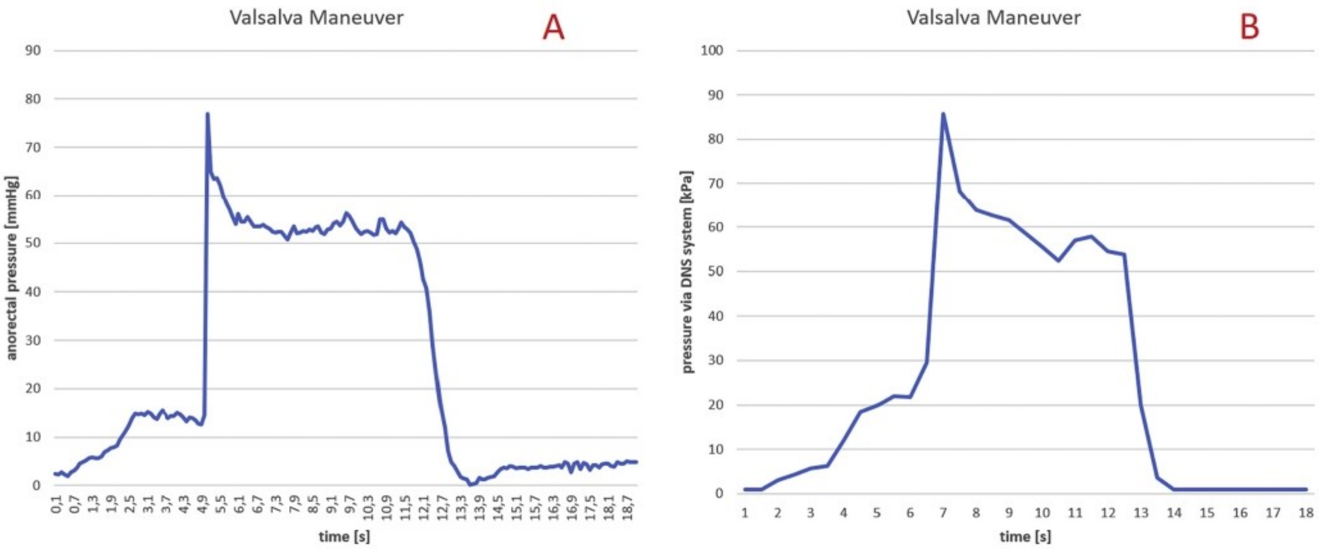

Fig. 2. Example of graphical visualization of the measured pressures (A: anorectal manometry, B: DNS Brace) during Valsalva maneuver scenario. A minor delay in DNS Brace measurement relative to ARM is caused by a minimal delay of AWT relative to IAP and by the fact, that DNS Brace measures AWT in 0.5 s. intervals while ARM measures IAP in 0.1 s intervals. Additionally, brace sensors identify only pressure changes over 1 kPa. These factors may cause negligible inaccuracy. The starting pressure before the maneuver is around 5 mmHg for ARM whereas the DNS system starts from zero and returns to zero after the maneuver. DNS Brace automatically reset to zero starting pressure for user friendly reasons. This has no impact on the results because all indirect measurement techniques are able to monitor the IAP changes rather than estimating the absolute IAP value (Tayebi et al., 2021).

both collected for 10 s during each of the five scenarios, and the average value of each measurement was used for statistical analysis.

The measured scenarios:

1) Resting breathing: The participant was breathing naturally in a standing position.
2) Valsalva maneuver: The participant was forcefully exhaling against closed nostrils and mouth (Talasz et al., 2012, 2011).
3) Müller maneuver: The participant was forcefully inhaling against closed glottis (Mattos Soares et al., 2009).
4) Instructed breathing (The diaphragm test): The participant was expanding the abdominal wall pushing as much as possible against

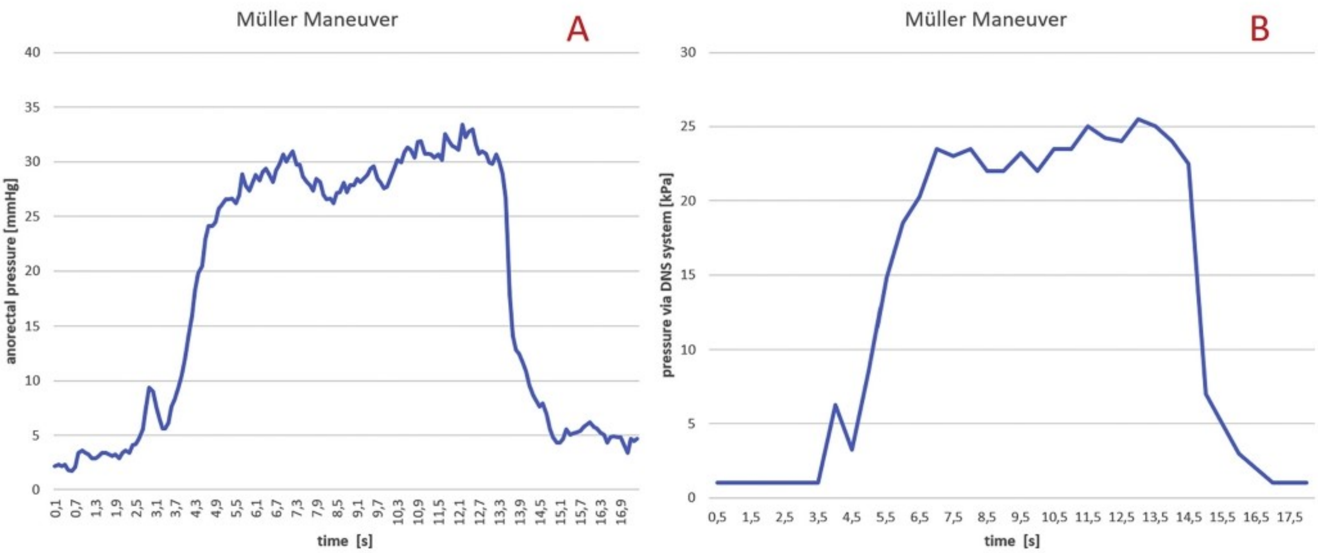

Fig. 3. Example of graphical visualization of the measured pressures (A: anorectal manometry, B: DNS Brace) during Müller maneuver scenario.

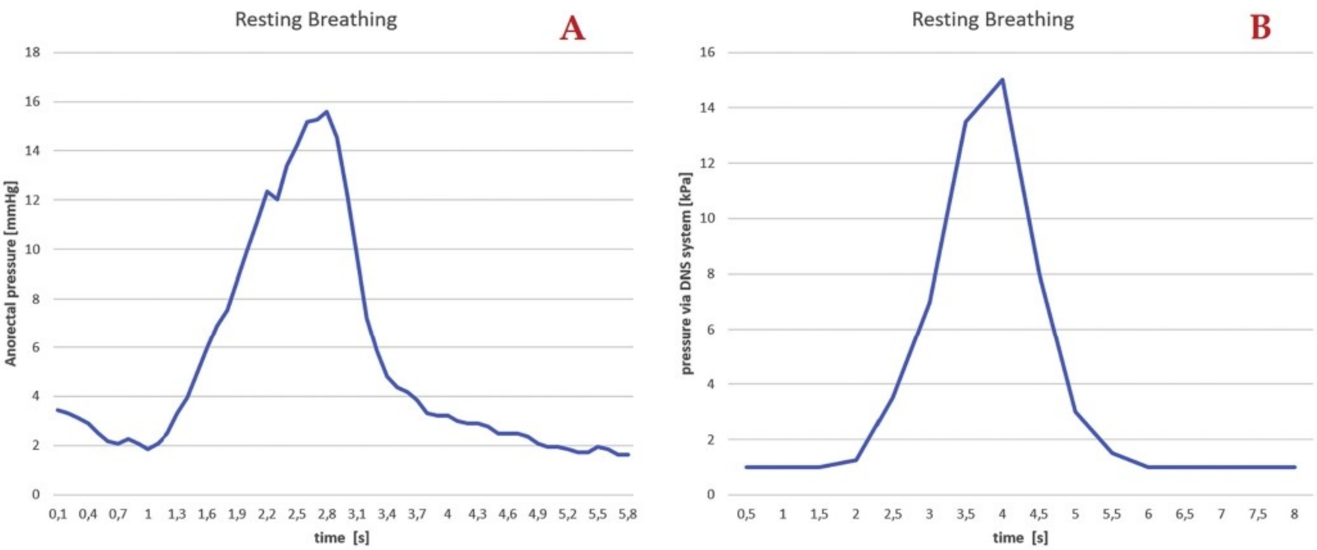

Fig. 4. Example of graphical visualization of the measured pressures (A: anorectal manometry, B: DNS Brace) during resting breathing scenario.

all four sensors both during inhalation and exhalation (Kobesova et al., 2020).

5) Holding a load of 20% of participant's body weight in hands in front of the trunk - loaded breathing (Fig. 1C).

2.5. Statistical analysis

Data analyses were conducted using the Statistical Package for the Social Sciences *v27.0 for Mac (IMBCorp, Armonk, NY)*.. Pearson's correlations and linear regression tests were used to assess the relationship between the 10-s mean anorectal manometry values and DNS Brace values under all five scenarios. Statistical significance was determined a priori at $p < 0.05$, and power analyses revealed in order to achieve a power of 0.80, 29 subjects were needed to identify a large effect size of 0.50 for Pearson's correlations, and 26 subjects were needed to achieve a large effect size of 0.35 for linear regression analyses. The strength of correlations were interpreted as weak (< 0.30), moderate (0.30–0.50), or strong (> 0.50), and the strength of regression predictions were interpreted as weak (< 0.02), moderate (0.15–0.35) or strong (> 0.35)

3. Results

Preliminary analyses showed linear relationships, with no outliers as assessed by scatterplots, but not all variables were normally distributed, as assessed by Shapiro-Wilk's test ($p < 0.05$). Data are mean ± standard deviation unless otherwise stated. Pearson's correlations demonstrated strong statistically significant positive relationships between anorectal manometry pressures and DNS Brace pressures, under all five scenarios: resting breathing: $r(31) = 0.735, p < 0.001$; Valsalva maneuver: $r(31) = 0.836$, $p < 0.001$; Müller's maneuver: $r(31) = 0.651$, $p < 0.001$; instructed breathing: $r(31) = 0.708, p < 0.001$; and loaded breathing: $r(31) = 0.921$, $p < 0.001$ (Table 2). Simple linear regression models established that anorectal manometry pressure could significantly be predicted from the DNS Brace values under all five scenarios: resting breathing: $F(1, 29) = 34.14, p < 0.001$; Valsalva maneuver: $F(1, 29) = 67.42$, $p < 0.001$; Müller's maneuver: $F(1, 29) = 21.29$, $p < 0.001$; instructed breathing: $F(1, 29) = 29.14, p < 0.001$; and loaded breathing: $F(1, 29) = 161.2$, $p < 0.001$ (Figs 5 - 9). Table 3 depicts all results from regression analyses.

Table 2
Correlations between Intra-Anal Manometer and DNS Brace Pressures. Values are Mean [Standard Deviation].

Condition	Manometric probe pressure	DNS Brace pressure	Pearson r	Sig
1-Resting Breathing	22.73 [12.38]	20.34 [11.68]	0.735	< 0.001*
2-Valsalva Maneuver	47.20 [27.09]	35.93 [20.19]	0.836	< 0.001*
3-Müller's Maneuver	35.92 [24.96]	20.87 [10.45]	0.651	< 0.001*
4-Instructed Breathing	34.72 [17.45]	26.57 [15.05]	0.708	< 0.001*
5-Loaded Breathing	36.35 [21.46]	30.97 [25.86]	0.921	< 0.001*

Note: DNS = Dynamic neuromuscular stabilization.
* Statistically significant correlation ($P < 0.01$).

4. Discussion

4.1. IAP measurement methods

Currently, various methods to measure the IAP are available. It can be monitored directly via sensors located intraperitoneally or in the inferior caval vein. Intra-vesical, intra-gastric intra-anal or intra-vaginal recording allow to measure the IAP indirectly (Malbrain et al., 2006; Wise et al., 2017). This study utilized intra-anal, i.e. measurement using anorectal manometry, which has been determined the safest and easiest method of assessment (Malbrain et al., 2013, 2006). Other methods posed different challenges, such as intra-vesical catheters may cause urinal infection and urethral trauma, intra-gastric measurement is uncomfortable for participants, and intra-vaginal measurement would exclude male participants. The intra-anal pressure measurement is a reliable way to monitor the IAP, although it does not match with the IAP as accurately as the intra-vesical pressure (Wise et al., 2017). There are only a few inconveniences of intra-anal pressure monitoring such as the presence of residual faeces, incorrect insertion of the probe and participant's embarrassment (Bhatia and Bergman, 1986; Pfeifer and Oliveira, 2006).

In a clinical practice, practitioners often palpate the abdominal wall assuming it to be a non-invasive and indirect way of IAP evaluation. The abdominal wall expands with the IAP increase (van Ramshorst et al., 2011). Palpation can be performed in the area above the inguinal ligament and in the superior lumbar triangle (Kobesova et al., 2020). Poor activation in these specific areas of the abdominal wall are commonly found in individuals with low back pain (LBP) (Frank et al., 2013; Kobesova et al., 2016). The same trunk sections were previously assessed by other researchers when evaluating abdominal wall activity in relation to IAP regulation (Kumar et al., 2012; Malátová et al., 2013; Novak et al., 2020). Therefore, the sensors are placed on the DNS Brace in the parts adhering to the abdominal wall above the inguinal ligaments and in the superior lumbar triangles. Here, only the attachments of the flat abdominal muscles are located and therefore the abdominal wall is easily accessible (Grevious et al., 2006).

Our in vivo correlations between IAP and AWT in asymptomatic individuals are in line with the study by Ramshorst et al. previously performed on corpses. Ramshorst used a special dynamometer to monitor AWT resulting from IAP changes in corpses, in which the IAP was changed artificially by insufflation (van Ramshorst et al., 2011). Ramshorst's study reports that AWT reflects the IAP. The findings from this study demonstrate significant correlations between the natural IAP regulation and AWT in all five measured scenarios with Pearson's coefficient ranging 0.651 to 0.921 which indicates strong correlations, with the ability to predict the IAP from the measured tension values.

4.2. Changes in IAP in response to respiration and postural load

The findings of the current study support prior experiments reported by Davis (Davis, 1959) and Cholewicki (Cholewicki et al., 1999), confirming that IAP increases with progressing demands on postural stability. The IAP increase results in the proportional activation of the abdominal wall which can be objectively monitored by the sensors or subjectively palpated in the area above the inguinal ligament and in the superior lumbar triangle. In other words, these results confirm that subjective palpation of the abdominal wall is an indirect evaluation of IAP.

Breathing has been shown to considerably influence IAP, trunk stability and movement (Bradley and Esformes, 2014). In this study, inhalation during resting breathing caused only slight increases in the

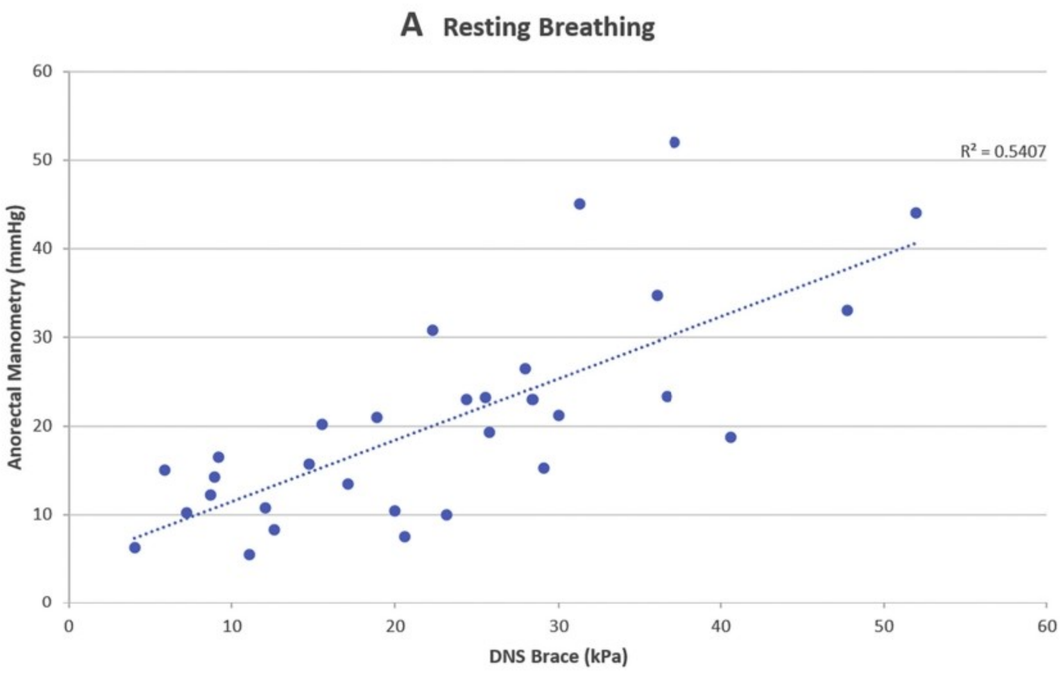

Fig. 5. Simple linear regression analysis of anorectal manometry values (mmHg) and DNS Brace values (kPa) measured during resting breathing.

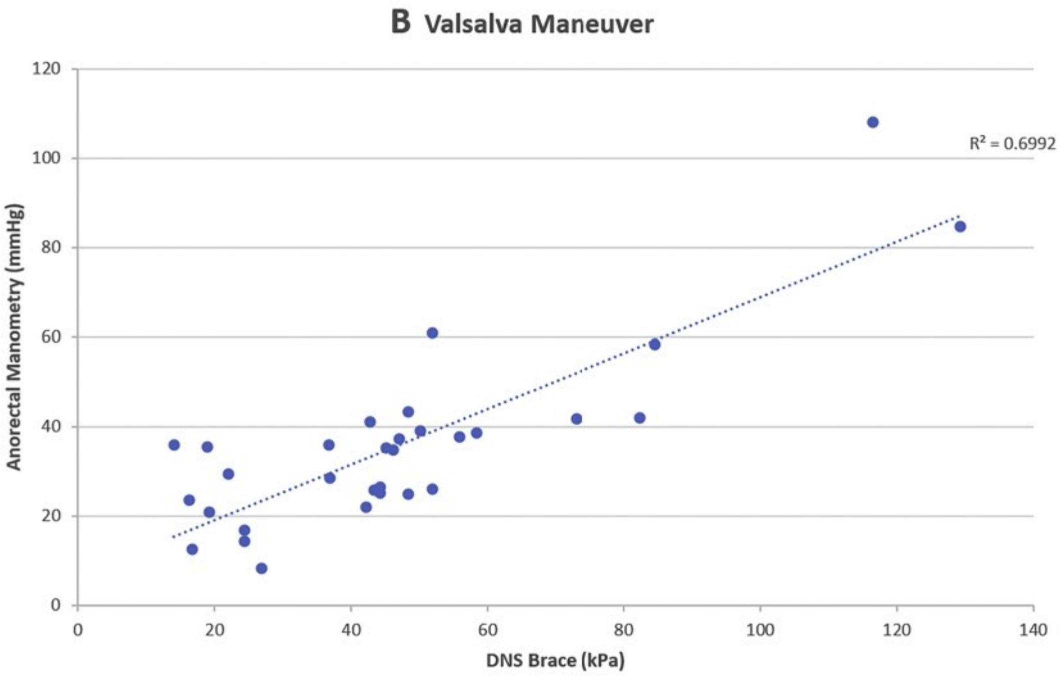

Fig. 6. Simple linear regression analysis of anorectal manometry values (mmHg) and DNS Brace values (kPa) measured during Valsalva maneuver.

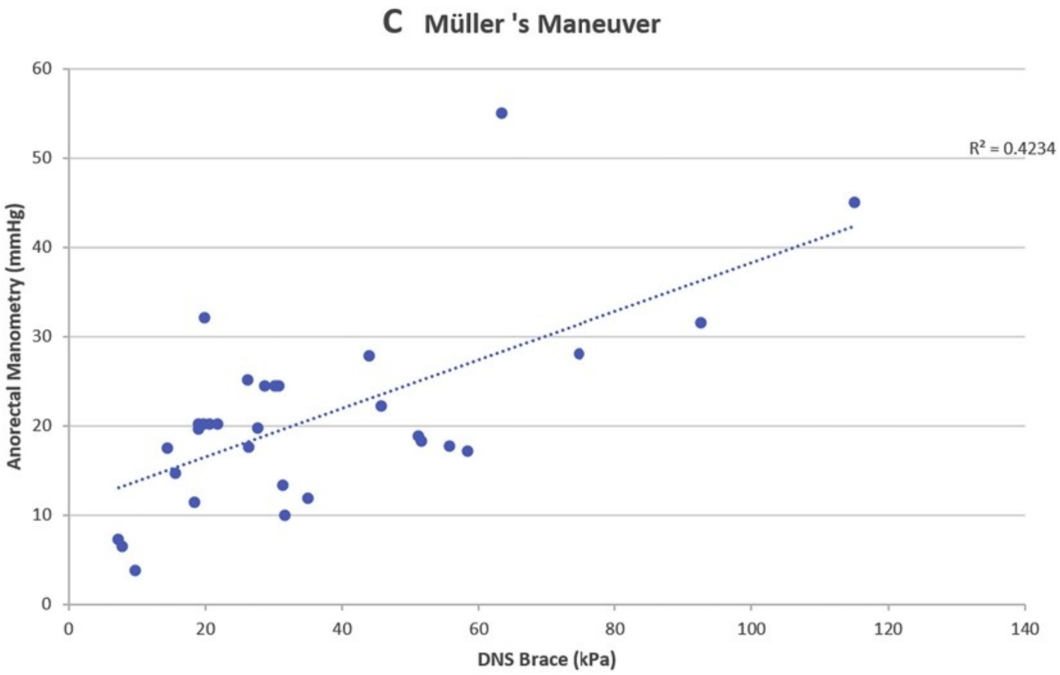

Fig. 7. Simple linear regression analysis of anorectal manometry values (mmHg) and DNS Brace values (kPa) measured during Müller maneuver.

IAP. During exhalation, the AWT and the IAP returned to the basic value. This physiological fluctuation of IAP is normal within the respiratory cycle. Permanent excessive resting IAP would cause organ function failure (Cobb et al., 2005; De Waele et al., 2011; Smit et al., 2016). In this study, the largest increase in the IAP was noted during the Valsalva maneuver. Perhaps this is due to the fact that the muscles of the torso do not have to perform a respiratory function during the Valsalva when the air is not flowing out of the body, the intra-thoracic pressure increases and the cranial displacement of the diaphragm is smaller than with a normal exhalation (Talasz et al., 2012, 2011). During the Müller maneuver, the intra-thoracic pressure is significantly reduced, the diaphragm descends towards the abdominal cavity but no air flows into the lungs (Kushida, 2013). In our study, Pearson's correlation coefficient was the smallest in this scenario (0.651) which was also the most difficult task for the participants to understand and perform. The instructed breathing represents the Diaphragm Test according to DNS concept. The participants voluntarily expand the abdominal wall towards all four sensors, keeping the abdominal cavity pressurized during the entire respiratory cycle (Kobesova et al., 2020). With this scenario, the participant must be able to combine the respiratory and postural functions of the diaphragm, which is a frequent problem in clinical practice (Kawabata et al., 2010; Shirley et al., 2003). It is speculated that

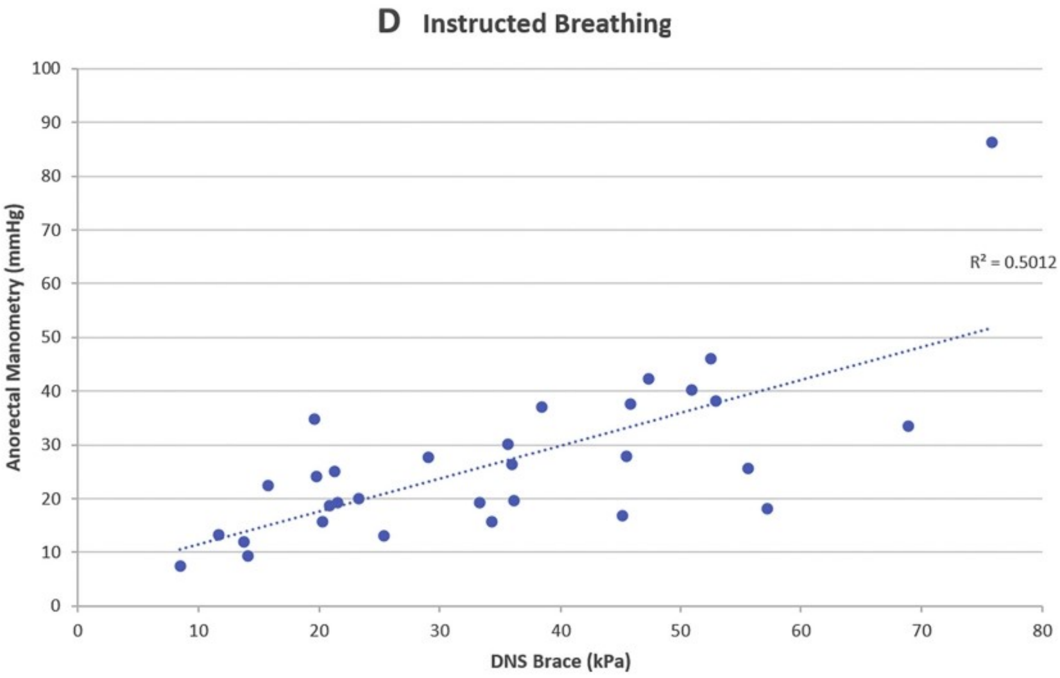

Fig. 8. Simple linear regression analysis of anorectal manometry values (mmHg) and DNS Brace values (kPa) measured during instructed breathing.

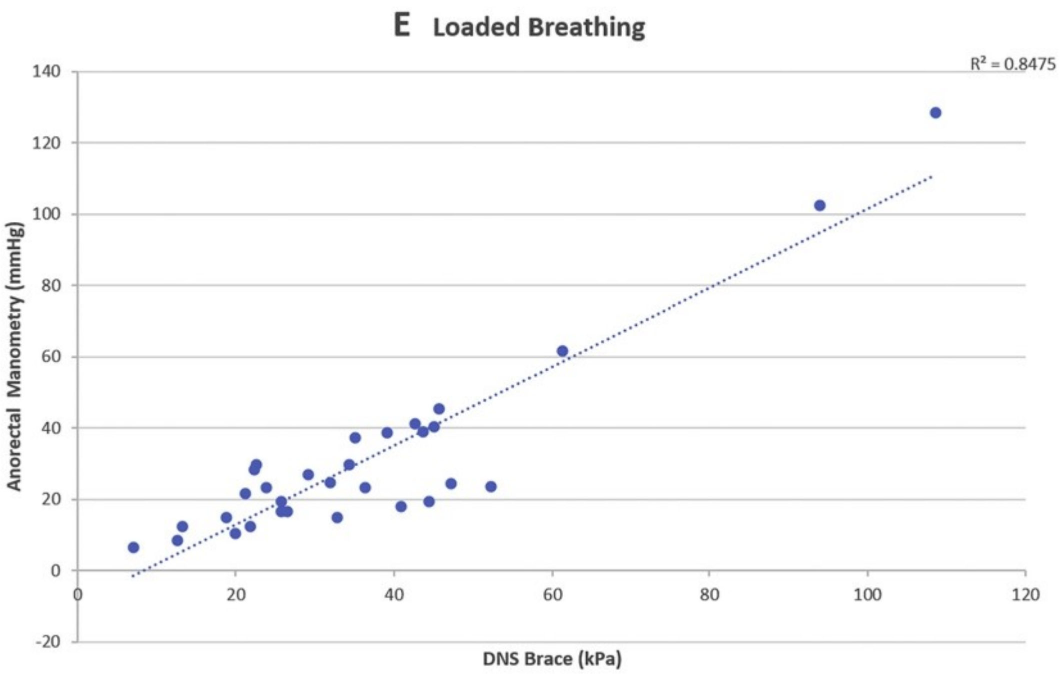

Fig. 9. Simple linear regression analysis of anorectal manometry values (mmHg) and DNS Brace values (kPa) measured during loaded breathing.

individuals unable to do so maybe in a greater risk of developing LBP in the future (Ostwal and Wani, 2014; O'Sullivan and Beales, 2007). During the last scenario, the participants were holding a barbell of a weight corresponding with 20% of body weight. This situation caused less IAP increase than the Valsalva maneuver but more than resting and instructed breathing and Müller maneuver. Other studies also report significant increases in abdominal muscle activity monitored by EMG (Ershad et al., 2009; Mesquita Montes et al., 2017) and in the IAP monitored by anorectal probe (Hodges et al., 2005; Tayashiki et al., 2015) during posturally challenging situations. With normal resting breathing, a decrease in the IAP during exhalation occurs. However, there is only slight pressure fluctuation within the respiratory cycle with postural loading when the IAP must be reflexively maintained on a higher level throughout the whole respiratory cycle. In this test, the correlation between the values obtained from the manometry and from the DNS Brace sensors was the strongest (Pearson $r = 0.921$). When holding a load, the stabilization strategy is purely reflexive, i.e. involuntary, and therefore diagnostically valuable in determining possible risks associated with poor trunk stabilization.

Table 3
Summary of Simple Regression Analyses for Predicting Intra-Anal Manometer Pressure using DNS Brace Pressure ($n = 31$).

Condition	B	$SE\ B$	R^2	Adjusted R^2	95% CI	Effect Size (f^2)
1-Resting Breathing	0.78	0.13	0.54	0.53	0.51, 1.05	1.18
2-Valsalva Maneuver	1.12	0.14	0.70	0.69	0.84, 1.40	2.32
3-Müller's Maneuver	1.55	0.34	0.42	0.40	0.87, 2.24	0.73
4-Instructed Breathing	0.82	0.15	0.50	0.48	0.51, 1.13	1.00
5-Loaded Breathing	0.76	0.06	0.85	0.84	0.64, 0.89	5.58

Note: DNS = Dynamic neuromuscular stabilization.
R^2 = R square: proportion of variance explained by model in sample.
Adjusted R^2: proportion of variance explained by model in population.

4.3. Methods to measure abdominal wall tension and abdominal wall activation

The DNS Brace helps to assess both voluntary control and reflex postural activation. It can be used as a feedback tool to train abdominal wall activation and the IAP fluctuations. The DNS Brace can be fixed to the trunk keeping all four sensors in stable contact with the abdominal wall thus allowing evaluation in various body positions. Future studies need to identify the AWT in other postural situations. Other devices like a pressure Biofeedback Unit (Lima et al., 2011) and muscle dynamometry (Malátová et al., 2013), designed to measure or train trunk muscles and lumbopelvic stability may not allow such positional variability. Electromyography (Marshall and Murphy, 2010) or ultrasound (Amerijckx et al., 2020) analyze mainly local activation of the abdominal muscles. The information from the four DNS Brace sensors monitor more global co-activation of all abdominal muscles. Based on the strong correlations identified with the DNS Brace and anorectal manometry it can be concluded that the DNS Brace presents a new simple and non-invasive method to evaluate IAP indirectly. The DNS Brace may prove to be useful in physical rehabilitation medicine and research to monitor AWT in response to postural-respiratory demands, and may help to objectivize therapeutic effects, while also providing biofeedback during self-treatment. In the ideal condition, the DNS system is able to track IAP fluctuations and not measure absolute values of IAP, and therefore would not be suitable for IAP monitoring at intensive care units.

4.4. Study limitations

This study has several limitations. An average value from the four DNS Brace sensors was calculated and used for statistical analysis. Therefore, possible asymmetric tension of the abdominal could not be taken into account. The current version of the DNS Brace is not commercially available, but sensors working on a similar principle called Ohm Track (Novak et al., 2020) can be purchased and used in a similar way. DNS Brace cannot be applied to any participants with very narrow or extremely wide waistlines, therefore a different version of the DNS Brace is needed to increase the variability in testing individuals with different corset circumferences. While BMI seems to have no impact on indirect IAP measurements (Chen et al., 2015), the thickness of the abdominal fat layer may play a role. The relationship between the AWT changes measured by the brace sensors and subcutaneous fat thickness measured by a caliper can be explored in future studies. The research was performed on 31 asymptomatic and rather young individuals. Further studies should investigate larger cohorts of individuals comprised of both asymptomatic and LBP or other musculoskeletal problems.

5. Conclusions

This study established strong correlations between IAP measured as the anorectal pressure through high resolution manometry with AWT measured by the DNS Brace. Such manometry values could be predicted through the measurement of AWT. Strong correlations were identified during various breathing modifications and also during postural stabilization situations when holding a load. It was confirmed that with progressing demands on postural stability, the IAP increases in a direct correlation with proportional tension of the abdominal wall. The AWT was identified by four DNS Brace sensors located above inguinal ligaments and in the upper lumbar triangle bilaterally. For clinical applications, subjective palpation may be an effective indirect evaluation of intra-abdominal pressure.

Credit authorship contribution statement

Jakub Novak: Conceptualization, Project administration, Methodology, Investigation, Data curation, Writing - original draft. **Jakub Jacisko:** Conceptualization, Methodology, Investigation. **Andrew Busch**: Data curation, Software, Writing - review & editing. **Pavel Cerny:** Conceptualization, Interpretation and analysis of data. **Martin Stribrny:** Conceptualization, Methodology, Investigation. **Martina Kovari:** Supervision, Writing - review & editing. **Patricie Podskalska:** Project administration, Data curation. **Pavel Kolar:** Conceptualization. **Alena Kobesova**: Conceptualization, Supervision, Writing - review & editing, Funding acquisition.

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Declarations of Competing Interest

None.

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6.3. Correlation between palpatory assessment and pressure sensors in response to postural trunk tests

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Correlation between palpatory assessment and pressure sensors in response to postural trunk tests

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Abstract.
BACKGROUND: The evaluation of postural trunk muscle function is a critical component of clinical assessment in patients with musculoskeletal pain and dysfunction. Postural activation of the trunk muscles has been evaluated by various methods. This study evaluates the correlation between subjective assessment of postural trunk muscle function with an objective measurement of abdominal wall expansion.
METHODS: Twenty-five healthy participants (16 women, 9 men, age 22.4 years) were assessed. The subjective assessment was performed by two experienced Dynamic Neuromuscular Stabilization (DNS) clinicians evaluating the quality of trunk stabilization using five postural stability tests through palpation and observation. Interrater reliability was determined using an intraclass correlation coefficients (ICC). Objective measurement was performed using a new device (DNS Brace) which externally measures abdominal wall pressure. Spearman rank correlations were calculated for both palpation and observation measures with DNS Brace data.
RESULTS: The interrater reliability (ICC2,k) estimates demonstrated moderate reliability in palpation measures for three DNS tests: Hip flexion test, Diaphragm test, & Intra-abdominal pressure regulation test (IAPRT) (ICC = 0.645–0.707). For observation measures, good reliability was found in IAPRT (ICC = 0.835), and three tests demonstrated moderate reliability: Hip flexion test, Diaphragm test, & Breathing Stereotype (ICC = 0.577–0.695). Correlation analysis demonstrated several moderate to strong correlations between palpation and DNS brace values (Assessor 1): IAPRT, $r_s = 0.580$, $p = 0.002$, Diaphragm test, $r_s = 0.543$, $p = 0.005$, (Assessor 2): IAPRT, $r_s = 0.776$, $p < 0.001$, Breathing Stereotype, $r_s = 0.625$, $p = 0.001$, Diaphragm test, $r_s = 0.519$, $p = 0.008$, Hip Flexion test, $r_s = 0.536$, $p = 0.006$, and Arm Elevation test, $r_s = 0.460$, $p = 0.021$. For observation, several moderate correlations were demonstrated with DNS brace values (Assessor 1): Arm Elevation test, $r_s = 0.472$, $p = 0.017$, (Assessor 2) Diaphragm test, $r_s = 0.540$, $p = 0.005$, IAPRT $r_s = 0.475$, $p = 0.016$, Hip Flexion test, $r_s = 0.485$, $p = 0.014$, and Arm Elevation, $r_s = 0.451$, $p = 0.024$.
CONCLUSION: Based on inter-rater reliability and DNS brace correlations with trained DNS professionals, the IAPRT, Diaphragm test, and Hip Flexion test may prove useful when assessing asymptomatic individuals. More research is needed in order to establish the utility of DNS brace and clinical testing both in asymptomatic and back pain populations. DNS tests must be supplemented by further examinations for definitive clinical decision making.

Keywords: Postural stabilization, breathing, abdominal muscles, intra-abdominal pressure, Dynamic Neuromuscular Stabilization

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1. Introduction

Evaluation of postural trunk muscle function is a critical component of clinical assessment in patients with musculoskeletal pain and dysfunction. Activation of the postural trunk muscles is essential for maintaining IAP (Intra-Abdominal Pressure) [1,2]. Appropriate IAP regulation secures stability of the lumbar spine [3,4]. Altered function of trunk muscles is associated with low back pain (LBP) [5,6] which is a major public health problem worldwide causing significant personal and financial burden [7]. Numerous studies suggest that trunk and lumbar spine stabilization exercises may help in LBP treatment and contribute to LBP prevention [8].

Postural activation of the trunk muscles has been evaluated by various methods such as ultrasonography [9], electromyography [9], pressure biofeedback unit [10], dynamometry [11] or direct IAP measurement [3,4]. Although some of these methods can measure the core activity or even IAP quite accurately, most of them serve for research purpose rather than clinical practice because the procedures may be uncomfortable for the patient, invasive, time consuming and often difficult to interpret the results. In routine clinical practice subjective assessment via various clinical tests is the most common way to evaluate postural function of the trunk muscles [12,13].

One concept offering a complete set of clinical tests to evaluate closely inter-related postural-respiratory functions [14] is Dynamic Neuromuscular Stabilization (DNS) [13]. DNS is a functional diagnostic and therapeutic approach based on human ontogenesis applying principles of movement and posture development during the first years of a healthy individual's life [15,16]. The complete set of DNS testing [13] captures the stereotype of postural stabilization and movement [17], respiratory pattern [14,18], functional joint centration [15] and segmental movement [19], while offering a functional treatment plan for musculoskeletal [20,21] or neurological patients [22]. Still, there is a need for more objective data to demonstrate the reliability of DNS procedures and to monitor the progress or improvements based on DNS principles.

Therefore, this study presents a new, non-invasive device called DNS Brace which objectively measures the expansion of the abdominal wall, a function which purportedly correlates with IAP changes and breathing [1]. Expansion of the abdominal wall related to IAP regulation is an important mechanism of trunk and spinal stabilization [14]. Additionally, this study examines the correlation between a clinician's subjective postural function assessment and objective measurement of the abdominal wall expansion using the DNS Brace.

2. Methods

2.1. Participants

The study was approved by the local ethics committee (Protocol number 17954, 8.1. 2020, Ethics committee of the Second Faculty of Medicine, Charles University and University Hospital Motol, Prague, Czech Republic). Participants were addressed via social media. Exclusion criteria were any symptomatic neurologic, orthopedic, respiratory or musculoskeletal disorder, spine or abdominal surgery, severe trauma during the last year, pregnancy, and undergoing DNS therapy in the past. In total 25 participants, 16 women and 9 men were involved in the study. Before the assessment, every participant received the same detailed information about the testing procedure. Every participant signed the informed consent. Basic descriptive data including gender, age, anthropometric data were recorded for each participant. Table 1 shows general characteristics for the whole group.

2.2. Instrumentation

The DNS Brace (Produced by Ortotika, FN Motol V Úvalu 84, Praha, (Fig. 1) which is mechanically configured as a trunk orthosis is equipped with four sensors working on a mechanical-pneumatic-electronic principle. For assessment, the brace fits tightly to bony structures allowing the expansion of soft tissues. The sensors are fixed on the inner wall of the brace. Two sensors are located on the brace parts adhering to laterodorsal sections (trigonum lumbale) of the abdominal wall and two are placed above the groin. The position of the sensors can be easily adjusted to fit each individual. The sensor heads are hemispheric in shape, allowing them to adhere to soft tissues in the monitored locations. Each sensor head contains an inner-air chamber and is made from silicone, which provides stable mechanical quality in a wide range of temperatures. The inner-air chamber is connected to a digital pressure sensor via a capillary tube. When recording measurements, each sensor's silicone head is deformed by the applied pressure, which causes a reduction of volume in the inner-air chamber, thus increasing pneumatic pressure in the inner capillary system. Pneumatic pressure is registered via an

Table 1
Participant's anthropometric characteristics. $n = 25$, 9 males, 16 females

	Age (year)	Height (m)	Weight (kg)	BMI (kg/m^2)	Waist (cm)
Mean	22.4	172.68	68.88	23.02	77.16
SD	1.76	7.26	8.66	1.58	5.98
Min	20	161	58	19.82	67
Max	25	190	85	25.85	90

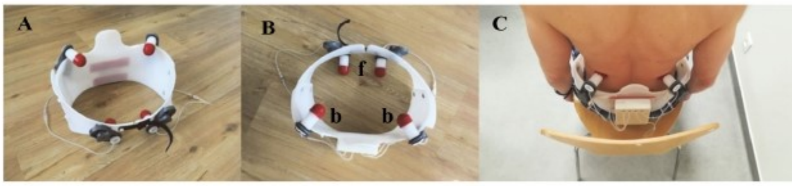

Fig. 1. DNS brace A. Front view; B. Top view, f – two sensors in the front, b – two sensors in the back; C. Back view, Brace on a man.

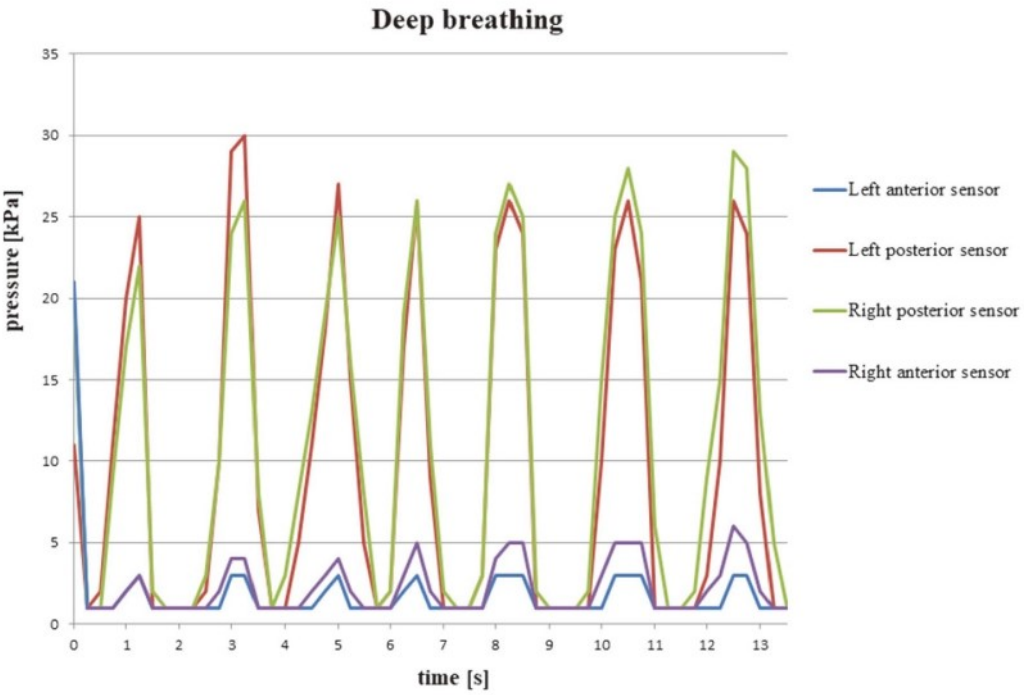

Fig. 2. Data from DNS Brace measuring deep breathing displayed in a graph.

auxiliary electric device (digital pressure sensor) on the orthosis. The sensors register the pressure exerted by the abdominal wall. The values recorded in kilopascals (kPa) are transferred via Bluetooth, stored and graphically displayed in a smart-phone device (Fig. 2). The sampling rate is 240 Hz.

2.3. Procedure

Participants ($n = 25$) were randomly assigned to two groups. Participants from group 1 ($n = 13$, female 8, male 5) were first assessed by the two DNS assessors in a random order (some participants were first assessed by assessor #1 and then by assessor #2 or vice versa), and subsequently by DNS Brace which was applied by another clinician. Participants from group 2 ($n = 12$, female 8, male 4) were first assessed by DNS Brace, and subsequently by the two DNS assessors in random order. The measurements were always performed under the same environmental conditions.

DNS assessors evaluated the five postural tests according to DNS (as described below) consecutively in

Fig. 3. Visual-analogue scale for subjective assessment of postural tests (the assessors made two lines on VAS – one for aspection, one for palpation).

the same order on each participant. Every participant was given exactly the same instructions before each test. After assessing all 5 tests by the first DNS assessor, the participant was assessed by the other DNS assessor, who gave the same instructions to evaluate each test. There was no time limit for the evaluation. Both assessors assessed each participant first by palpation and then visually using VAS (visual analogue scale) from 0 (no activation) to 100 (ideal activation) [23] (Fig. 3). Palpation by DNS assessors was performed at the same body regions where the DNS Brace sensors were placed, i.e. in trigonum lumbale bilaterally and above the groin bilaterally. DNS tests were reported as reliable assessment methods in other research projects previously [24].

2.4. *Subjective assessment*

Five DNS postural tests were performed by each participant and evaluated by two experienced assessors (certified DNS instructors) by palpation and inspection using VAS from 0 to 100 points where 0 represents absolute inability to perform required activity and 100 represents ideal activation (Fig. 3).

During all five tests the participants were seated, their hips and knees flexed in 90° angle, feet touching the ground while keeping spine upright and shoulders relaxed. With each participant the tests were evaluated in the following order:

1. Breathing stereotype test. (Fig. 4) The participant was instructed to take five deep breaths. The assessor first palpated the activation in the lower intercostal spaces and below the lower ribs bilaterally and then above the groin. Then, the assessor performed visual observation focusing on lower ribs and shoulder movement.
2. Intra-abdominal pressure regulation test. (Fig. 5) The assessor palpated bilaterally the lower abdominal sections above the groin. The participant was instructed to activate the IAP by pushing against assessor's fingers. Amount and symmetry of activation is assessed by palpation. Then, visual observation of abdominal contour, umbilicus and shoulder movement was performed.
3. The diaphragm test. (Fig. 6) The assessor was positioned behind the participant palpating bilaterally below participant's lower ribs. The participant was instructed to take a deep breath and push towards assessor's fingers to activate the abdominal wall. The assessor evaluated the amount and symmetry of activation of the abdominal wall. Then, the assessor visually observed lateral movement of the lower ribs while monitoring the spine (upright and stable) and the presence of shoulder movement or pathological synkinesis (Fig. 6).

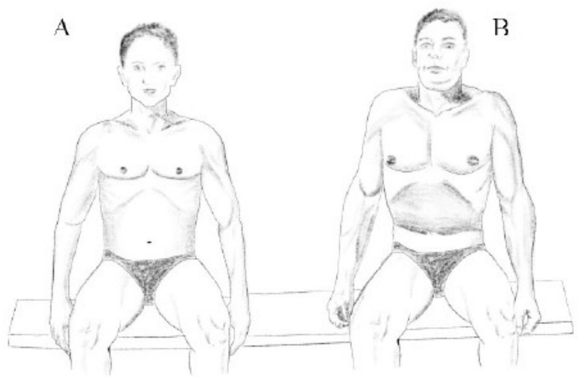

Fig. 4. Breathing stereotype test. A. Optimal pattern. Spine upright, trunk in neutral position, relaxed auxiliary breathing muscles, proportional expansion of abdominal wall occurs with inhalation. B. Pathological stereotype. The chest moves superiorly, shoulders moves superiorly and into protraction during inhalation, insufficient or no expansion of the abdominal wall.

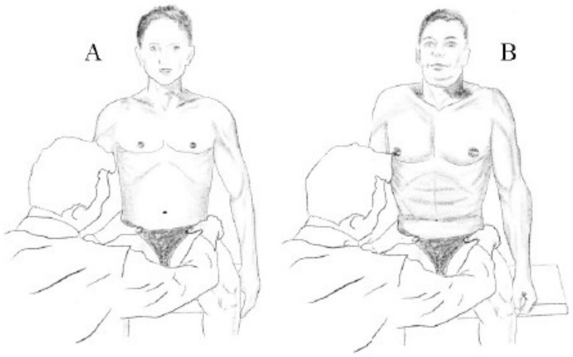

Fig. 5. Intra-abdominal pressure regulation test. A. Optimal pattern. Proportional tensing of abdominal wall in all sections. B. Pathological stereotype. Inability to expand lower abdominal wall, asymmetrical activation, overactivity of upper rectus abdominis muscle, ribcage elevation.

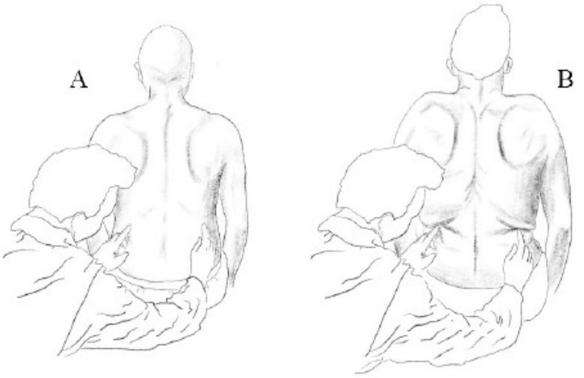

Fig. 6. Diaphragm test. A. Optimal pattern. Abdominal wall eccentric expansion, upright spine, without shoulder movements cranially. B. Pathological stereotype. Inability to expand latero-dorsal parts of the abdominal wall, asymmetrical activation, rib cage or shoulder elevation, substitutive mechanism with spinal kyphosis compensating for lack of eccentric abdominal wall activation.

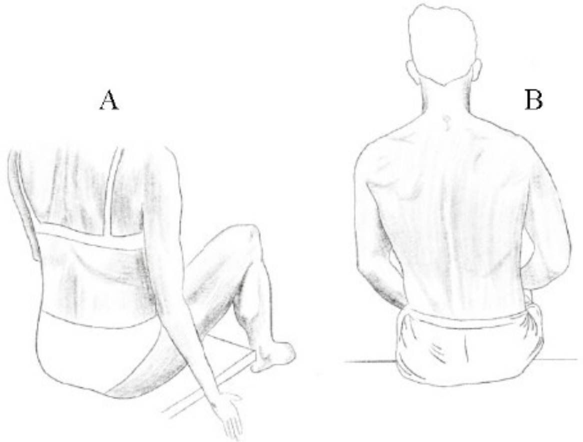

Fig. 7. Hip flexion test. A. Optimal pattern. Chest and pelvis in neutral position, spine upright. B. Pathological stereotype. Inability to keep the spine upright and pelvis stable, lateral shift of the trunk.

4. Hip flexion test. (Fig. 7) The assessor instructed the participant to slowly lift up right leg (approximately 10 to 20 cm) above the ground. Participant breathed naturally while maintaining this position. The activity of the latero-dorsal sections of abdominal wall was assessed bilaterally by palpation (as in diaphragm test). Then, any spinal and pelvic movements were assessed by visual inspection.
5. Arm lifting test. (Fig. 8) The participant lifted a dumbbell that corresponded to 20% of the body weight. Elbows were flexed to 90° and participant breathed naturally in this position. The assessor palpated bilaterally the abdominal wall activation first in trigonum lumbale, then above the groin.

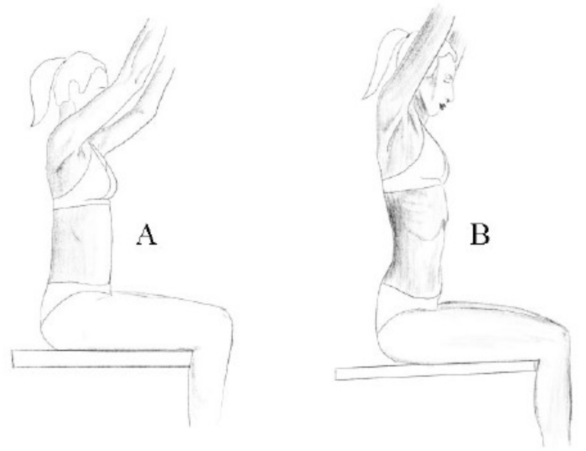

Fig. 8. Arm lifting test. A. Optimal pattern. Ribcage in neutral position, thoracolumbar junction stable, symmetrical expansion of abdominal wall. B. Pathological stereotype. Chest elevation, thoracolumbar instability, hyperlordosis of the lumbar spine.

Spinal or pelvic movements were assessed visually.)

All DNS tests were performed according to the detailed procedures described by Kobesova et al. 2020, which include all signs of optimal and abnormal presentations [13].

2.5. DNS Brace measurements

The DNS Brace was applied by another clinician and was attached around the participant's trunk. The activity of the abdominal wall was monitored during the same five DNS tests and in the same order as with the subjective assessment. The same instructions were given for DNS Brace measurement as for the subjective testing. The sensors were always calibrated to 0 kPa in resting exhalation position prior to each measurement. Afterwards the participants were instructed to take two natural breaths and then the test was performed and the abdominal wall activity recorded. A total of 3 to 7 breathing cycles were recorded (recording time was between 6 to 20 seconds depending on individual breathing speed). Afterwards, the average pressure against all four sensors was calculated and used for correlation with the subjective clinical assessment. The assessors were not allowed to view results received from the DNS Brace measurements nor were they allowed to consult each other during testing.

2.6. Statistical analysis

Descriptive data were calculated, including means

Table 2
Interrater reliability of different DNS tests using palpation and observation ($ICC_{2,k}$)

DNS test	Palpation			Observation		
	ICC	95% CI	Sig	ICC	95% CI	Sig
1-Breathing stereotype	0.446	(−0.258, 0.756)	0.078	0.695*	(0.308, 0.866)	0.003
2-IAPRT	0.707*	(0.334, 0.871)	0.002	0.835**	(0.626, 0.927)	0.000
3-Diaphragm test	0.646*	(0.197, 0.844)	0.007	0.668*	(0.246, 0.854)	0.005
4-Hip flexion test	0.645*	(0.194, 0.843)	0.007	0.577*	(0.04, 0.814)	0.020
5-Arm elevation	0.308	(−0.570, 0.695)	0.187	0.464	(−0.217, 0.764)	0.067

Note: DNS = Dynamic neuromuscular stabilization; ICC = Intraclass correlation coefficient; IAP = Intra abdominal pressure regulation test; Both examiners were trained DNS professionals. *Denotes: Moderate reliability. **Denotes: Good reliability.

Table 3
Correlations of DNS instructor values with average DNS brace values in five DNS tests (mean [standard deviation])

DNS test	DNS brace average values	Palpation			Observation		
		Score	Spearman r_s	Sig	Score	Spearman r_s	Sig
DNS Assessor 1							
1-Breathing stereotype	4.89 (3.18)	70.28 (19.43)	0.443	0.026	65.56 (20.85)	0.290	0.159
2-IAPRT	12.19 (8.47)	84.12 (14.27)	0.580	0.002*	76.88 (16.25)	0.380	0.061
3-Diaphragm test	11.73 (9.11)	76.16 (17.06)	0.543	0.005*	71.32 (16.86)	−0.105	0.616
4-Hip flexion test	6.28 (5.52)	65.44 (19.53)	0.338	0.009*	70.20 (17.34)	−0.039	0.852
5-Arm elevation	9.44 (8.80)	77.12 (14.12)	0.303	0.142	75.80 (10.91)	0.472	0.017*
DNS Assessor 2							
1-Breathing stereotype	4.89 (3.18)	43.60 (13.32)	0.625	0.001*	41.68 (15.87)	0.342	0.094
2-IAPRT	12.19 (8.47)	53.40 (20.58)	0.776	< 0.001*	47.60 (19.35)	0.475	0.016*
3-Diaphragm test	11.73 (9.11)	52.40 (16.83)	0.519	0.008*	49.64 (21.75)	0.540	0.005*
4-Hip flexion test	6.28 (5.52)	47.20 (13.00)	0.536	0.006*	45.68 (15.23)	0.485	0.014*
5-Arm elevation	9.44 (8.80)	46.08 (15.79)	0.460	0.021*	45.68 (20.43)	0.451	0.024*

Note: DNS = Dynamic neuromuscular stabilization; IAPRT = Intra-abdominal pressure regulation test; Both examiners were trained DNS professionals. *Statistically significant correlation (Bonferroni Correction $P < 0.025$).

and standard deviations (SD) for each DNS assessor's palpation and observation using the VAS, and the DNS brace values. Interrater reliability was determined using intraclass correlation coefficients ($ICC_{2,k}$) and their 95% confidence intervals (CI) between the two DNS assessors' measures of either palpation or observation for all five DNS tests based on a mean-rating ($k = 2$), consistency, 2-way random model. Reliability was defined as poor (ICC < 0.50), moderate (ICC 0.50–0.75), or good (ICC > 0.75). Spearman's rank order correlations were used to analyze the relationship between different DNS assessors measures with the average DNS Brace values. The strength of correlations were interpreted as weak (< 0.3), moderate (0.4–0.6), or strong (> 0.7), as reported by Akoglu [25]. The alpha level used for significance, with Bonferroni corrections, was set a priori at $p < 0.025$. All data was analyzed using SPSS statistical package v26 (SPSS Inc, Chicago, IL).

3. Results

Descriptive data for all participants are presented in Table 1. Not all variables were normally distributed, as assessed by Shapiro-Wilk's test ($p < 0.05$). Interrater reliability ICC estimates are shown in Table 2. For palpation, moderate reliability was demonstrated duirng three DNS tests: Hip flexion test, Diaphragm test, & IAPRT (ICC = 0.645–0.707). For observation, moderate reliability was again demonstrated in three tests: Hip flexion test, Diaphragm test, & Breathing Stereotype (ICC = 0.577–0.695) while a good reliability was found in IAPRT (ICC = 0.835).

All correlational data with 95 % confidence intervals are presented in Table 3. For DNS Assessor 1, palpation demonstrated moderate correlations between the DNS brace values with IAPRT, r_s (23) $= 0.580$, $p = 0.002$ and the Diaphragm test, r_s (23) $= 0.543$, $p = 0.005$ while observation demonstrated a lower correlation with the Arm Elevation test, r_s (23) $= 0.472$, $p = 0.017$. For DNS instructor 2, palpation demonstrated a strong correlation for for IAPRT, r_s (23) $= 0.776$, $p < 0.001$ and modetate correlations for the Breathing Stereotype, r_s (23) $= 0.625$, $p = 0.001$, Diaphragm test, r_s (23) $= 0.519$, $p = 0.008$, and Hip Flexion test, r_s (23) $= 0.536$, $p = 0.006$. A lower correlation was demonstrated with the Arm Elevation test, r_s (23) $= 0.460$, $p = 0.021$. Observation for DNS Assessor 2 demonstrated moderate correlations in the Diaphragm test, r_s (23) $= 0.540$, $p = 0.005$, IAPRT r_s (23) $= 0.475$, $p = 0.016$, Hip Flexion test, r_s (23) $= 0.485$, $p = 0.014$, and Arm Elevation, r_s (23) $= 0.451$, $p = 0.024$.

4. Discussion

Trunk stabilization analysis is critical part of clinical assessment. Postural function is closely related to movement and locomotion; mobility and stability form a functional unit that is under the constant control of central nervous system [26]. Another function closely related to trunk stabilization is respiration. The respiratory stereotype affects trunk muscle coordination and modifies the movement [27] therefore specific breathing instructions form a critical part of many stabilization exercise protocols [28,29]. Some studies indicate, that impaired postural control is associated with chronic low back pain [30]. Trunk stabilization training is often applied to treat and prevent back pain and other musculoskeletal problems and injuries [31].

The first step to analyze the influence of postural stabilization training on movement performance and musculoskeletal pain is to define the optimal pattern of postural stabilization. Due to extreme postural variability the exact definition of optimal posture is still ambiguous with each author defining the ideal posture differently [32–34]. One concept that aims to define optimal postural stabilization is Dynamic Neuromuscular Stabilization [35]. This DNS concept derives an ideal stabilization stereotype from genetically predetermined developmental patterns observed during normal early human ontogenesis. DNS offers a set of a functional diagnostic tests and evaluation to monitor a patient's posture [13]. However, the reliability of DNS clinical tests has not been demonstrated yet. This study correlates subjective assessment via five DNS tests performed by two experienced DNS clinicians with objective measurement of abdominal wall activity using new device called DNS Brace. The correlation between the subjective DNS assessments and objective measurement of abdominal wall expansion may help to determine the reliability of clinical DNS tests. At the same time this study reports interrater reliability for the five DNS tests. Additionally, this study introduces a new, simple and non-invasive device to measure the activity of the abdominal wall.

For both palpation (ICC $= 0.707$) and observation (ICC $= 0.835$) assessments, the IAPRT test demonstrated the best reliability between assessors. We identified moderate interrater reliability for both palpation and observation for the Diaphragm and the Hip Flexion test. Considering the complexity of DNS assessment, which emphasizes much detail and nuance both in palpation and observation assessment, the findings of moderate-good ICC's for 3/5 DNS tests was encourraging. These findings are similar to other well established systems, such as Mechanical Diagnosis and Therapy (MDT), where reported inter-rater reliability ranges from 0.11 to 1.00 [36]. Much more reasearch is needed to establish the relevance of DNS testing both in normal cohorts and in populations with various musculoskeletal problems.

The results of this study confirmed a positive correlation between objectively measured expansion of the abdominal wall and subjective palpatory assessment of postural trunk muscle function according to the DNS approach. For assessor 1, statistically significant correlation was identified for three DNS tests (IAPRT, Diaphragm and Hip Flexion test) and for assessor 2, palpation significantly correlated with all 5 DNS tests Brace measurements. The increase in pressure against the sensors was the highest in the situations when the measured participant was instructed to activate the IAP, i.e. when he or she had to push specifically against the sensors above the groin (IAPRT; average pressure $= 12.19$ kPa) or against the sensors placed in trigonum lumbale (diaphragm test; average pressure $= 11.73$ kPa). The third highest value was recorded during the arm elevation test holding the weight (average pressure $= 9.44$ kPa). The hip flexion test required 6.28 kPa average pressure increase only, yet such change was appropriately recognized by palpating assessors. During all these tests positive correlation between subjective and objective assessment was confirmed. The only exception was the breathing stereotype test where significant correlation between objective DNS Brace testing and subjective palpatory assessment was reached in one assessor only (see Table 2). During the breathing stereotype test the lowest average pressure increase (4.89 kPa) was measured by DNS Brace. It can be assumed that the smaller the change in the activation, the more difficult it is to estimate the amount of change by mere palpation.

Based on these results, instructed activation tests such as IAPRT or the Diaphragm test appear potentially useful in evaluating trunk stabilization function in clinical practice. Still, such tests need to be supplemented by further examinations for definitive clinical decision making. Surprisingly, lifting the weight corresponding to 20% of the participant's body weight evoked less postural stabilization activity than an instructed increase in IAPRT. Apparently, in healthy individuals such weight does not require much activity of the abdominal wall. This result further supports the study published by Essendrop et al. who report IAP increase from 0 to 40% when holding a load of 15% body weight [4].

The DNS Brace measures both voluntarily controlled and automatic subconscious postural activation. We can either instruct the individual to activate their abdominal wall pushing against the sensors, thus the brace can also be used for feedback training or we can monitor spontaneous level of activation during various movements. Both situations may be convenient in clinical practice and in research. Advantages of using the DNS Brace lie in it's fixed position of all 4 sensors that maintains contact with the trunk allowing the assessment in various positions and when moving. Such modifications may not be available when using other devices designed to measure and train abdominal muscles and lumbopelvic stability such as a Pressure Biofeedback Unit [37] or ultrasound which analyze mainly local activation of the abdominal muscles. The information from the four DNS Brace sensors is a more global monitoring of abdominal muscle co-activation. Also, it is very easy to apply the DNS Brace and to record and analyze results. Unlike electromyography, ultrasound or direct IAP measurement techniques, there is no need for special personnel training.

The entire assessment took approximately 8 minutes with each assessor, i.e. 24 minutes all together (2 subjective assessments + DNS brace assessments). The measurement order between assessor 1, 2 and DNS Brace was random to exclude the influence of any motor learning. The participants considered the examination to be both physically and mentally easy. The DNS Brace measurement starts from a fully relaxed state that does not require any pre-tensioning. In a study using a Pressure Biofeedback Unit, participants were instructed to maintain the target pressure range (40 ± 10 mmHg) [38]. This may exclude some individuals who are unable to reach such starting pressure. The DNS brace does not require any minimum prerequisite pressure to start the measurement, making the procedure simple, convenient and clinically useful. The DNS Brace measurement range is 0 to 500 kPa. The values measured by the brace are absolute thus comparable in time or among raters.

Correlation and statistical significance for palpation was in most cases better than that for observation. Palpation is an integral skill forming the vital component of many hands-on clinical examinations [39] including DNS concept. The results of this study support the use of the DNS tests described above when performed by skilled DNS clinicians. In this study the tests were evaluated by experienced DNS clinicians with more than five years clinical experience. This is an important aspect to consider since the palpation accuracy is closely related to examiner's experience and training [40]. To our knowledge this is the first study correlating subjective assessment of postural function of the trunk muscles with objective measurement of the abdominal wall expansion. The inspection should rather be complementary to palpation.

Future studies should investigate the correlation between abdominal wall expansion and direct IAP measurement to find out if DNS brace can actually replace invasive and uncomfortable techniques of direct IAP monitoring such as intravesical, anal or vaginal pressure measurements. Also, inter- and intra-rater reliability for DNS Brace needs to be established. Finally, the relationship between LBP and abdominal wall expansion needs to be explored as well as the effect of abdominal wall training. In the future DNS Brace may become a useful clinical and research tool.

There are some limitations to this study. First, this study was done in asymptomatic individuals. It is unknown if such DNS tests would show similar results in LBP patients or in individuals with other musculoskeletal disorders. Future studies in patients with LBP are warranted. Second, the average pressure against all four sensors was calculated and used for statistical analysis and the symmetry of the abdominal wall expansion was not considered. The brace could not be properly used in one extremely slim individual who had to be excluded from the study. In the future, smaller versions of DNS Braces will be constructed. Finally, DNS tests were assessed by DNS professionals (DNS instructors) with more than 5 years DNS experience. Future research could compare novice pracitioners with experienced, to learn differences.

5. Conclusion

Based on interrater reliability and DNS brace correlations with trained DNS professionals, the IAPRT, Diaphragm test, and Hip Flexion test may be useful for clinicians when assessing normal individuals. More research is needed in order to establish the utility of DNS brace and DNS clinical testing both in normal and back pain populations.

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Ethical considerations

The study was approved by the local ethics committee (Protocol number 17954, 8.1. 2020, Ethics committee of the Second Faculty of Medicine, Charles University and University Hospital Motol, Prague, Czech Republic). Before the assessment, every participant received the same detailed information about the testing procedure. Every participant signed the informed consent.

Conflict of interest

The authors have no conflict of interest to declare.

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6.4. The significance of intra-abdominal pressure on postural stabilization: A low back pain case report

THE SIGNIFICANCE OF INTRA-ABDOMINAL PRESSURE ON POSTURAL STABILIZATION: A LOW BACK PAIN CASE REPORT

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ABSTRACT

Intra-abdominal pressure is a hydraulic pressure within the abdominal cavity. Previous studies confirmed its direct association with both spinal stability and spinal unloading. The literature review part of the paper summarizes intra-abdominal pressure physiology and pathophysiology and explains the underlying mechanisms of intra-abdominal pressure regulation and its effects on the human body, especially spinal stability. Current methods of invasive and non-invasive intra-abdominal pressure measurement are described in detail. Second part of a paper presents a case report of a competitive athlete suffering from low back pain. The functional assessment and treatment focused on quality of patient's trunk stabilization. Training following principles of Dynamic Neuromuscular Stabilization resulted in better ability to activate abdominal wall muscles which is a critical mechanism of intra-abdominal pressure regulation and in this case caused significant low back pain reduction. The effect of the therapy was evaluated by DNS Brace which measures activity of the abdominal wall, thus intra-abdominal pressure indirectly, along with clinical Dynamic Neuromuscular Stabilization assessment tests.

Keywords: Intra-abdominal pressure, diaphragm, abdominal wall, spinal stability, objectification of postural stabilization

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INTRODUCTION

Stabilization of the lumbar spine - physiology

Postural stabilization is necessary for human body movement (1). External forces affect the human body during each movement. The body responds with the formation of internal forces mainly by muscular activity. This is so-called postural activity (2). The abdominal cavity is the space limited by the diaphragm superiorly and the musculo-aponeurotic perineum inferiorly, the lumbar spine posteriorly and the walls of the abdominal cavity anterolaterally (3). Postural activity is represented by strengthening/stabilizing function of these muscles and its ability to create intra-abdominal pressure IAP (4). It is all under the control of the central nervous system (CNS). The consequences of the pathological action of internal forces are often underestimated and the measurement options are still limited. The evaluation of IAP may be useful in a variety of clinical outcomes (5).

The postural role of IAP has been subject to research for almost 100 years. Dating back to 1923, Keith et al. suggested that IAP may affect spinal loading (6). In 1942 Bradford a Spurling published a study stating that spinal erectors put a 680 kg load on the spine during movement (7). In 1957 Bartelink experimented with a stress tests on intervertebral discs reporting structural damage occurring at the level of 136 kg load (8). In 1959

Davis reported IAP increase during load lifting (9). Without any compensatory unloading mechanism, the spine and especially the intervertebral discs would easily be damaged with every strenuous movement. Ground-breaking studies conducted by Hodges and colleagues have confirmed that IAP alone without any trunk muscle activity increases the stability of the lumbar spine, protects the spine from excessive loading, reduces axillary compression, and transfers the load to a larger area (4,10). For the stability in the lumbar spine is necessary proper coactivation between previously mentioned muscles that regulate IAP such as the diaphragm, pelvic floor muscles, abdominal muscles and spine extensors (4,11). It is important to mention that the diaphragm not only provides respiration and sphincter function but also a postural function (12,13). Electromyography (EMG) has shown that diaphragmatic contraction is modulated by postural and ventilation requirements (12). If the diaphragm contracts physiologically, the central tendon of the diaphragm drops inferiorly, creating a pressure gradient that drives air into the lungs and with the help of pelvic floor and abdominal wall activity increases the pressure in the abdominal cavity (14,15).

Activation of the trunk muscles keeps all segments of the spine in a biomechanically neutral position during movement (8). The pelvis and lumbar spine are reflexively stabilized before limb movements (12,16). Even if IAP is an important phenomenon in rehabilitation and is often studied, its specific function and role remains unclear (17,18). An obstacle in the studying IAP is the measurement complexity in experimental conditions especially in vivo. Many authors have already described the positive effect of IAP on spinal stability and spinal unloading but its importance still needs to be objectively studied (18).

Although several studies (4,11,19,20) have shown a connection between the increased IAP and spinal stability, it is not entirely clear whether this mechanical support for the spine is due to the increased IAP or the abdominal muscle activity itself which contributes to IAP (4). According to Mokhtarzadeh et al., the relative role of the IAP in spine mechanics has remained controversial and IAP alone without current muscle co-activation is not sufficient (15). On the other hand, Hodges et al. showed in their study that the stiffness of the lumbar spine during various functional movements is increased when IAP is elevated even without simultaneous muscle contraction (3). They suggest that IAP may be a beneficial tool for the CNS to increase spinal stability in all directions (4). Similarly, Stokes et al. reported that elevated IAP increased lumbar spine stability regardless of the primary muscle involved (18). Among others, Hodges et al. also described the fact that crura of diaphragm, by its contraction, causes direct traction of the lumbar spine in the area of their attachment and it promotes the effect of IAP (4). McGill et al. created a theory that elevated IAP increases lumbar spine stability by limiting intervertebral rotation and translation (16). According to these authors, the IAP helps to maintain the correct position of the moving parts of the spine by minimizing, or even completely eliminating, very small movements of shear forces in the area of the facet joints. This hypothesis could be a possible reason why patients, who are forced to move even with severe lumbar spine pain, hold their breath (21).

The lumbar spine complex is adapted to carry an external load. Stress is transmitted to the solid bodies of the vertebrae and relatively elastic disks. Excessive mechanical loading leads to damage to the intervertebral discs (22). Arshad et al. showed in a biomechanical model that IAP significantly reduced the compressive forces on the spine and at the same time reduced the need for muscle force involvement (23). According to some authors, higher IAP values lead to spinal relief, but maximum challenging activation such as the Valsalva maneuver have got the opposite effect due to the hight levels of muscle coactivation (24). However, Stokes et al. argue that the extension effect of IAP is greater than the flexion moment created by the abdominal wall muscles. In a biomechanical model of the spine, they have shown that IAP has the effect of relieving the spine in all directions of movement (18).

Other authors suggest that IAP creates a force caudally against the pelvic floor and cranially against the diaphragm, thus creating an extension moment of the spinal (4). Although IAP alone does not produce spine extension, it is associated with an antagonistic co-activation of flexors and extensors that increases the stability and strength of the spine (4). In addition, according to Daggfeldt et al., this mechanism could help reduce lumbar spine overloading indirectly by creating an extension moment thus reducing the need for spinal extensors activation (25). This thought is also supported by Cholewicki et al. that IAP is active in movements that require trunk strength for extension such as lifting objects or jumping can increase the stability of the spine without simultaneous co-activation of the spinal erectors (20). In order to achieve the greatest possible spinal protection, the cross-section of the lumbar part of the trunk must be as large as possible. The diaphragm and the pelvic floor must work exactly opposite each other (25). According to some authors, it is also important that IAP maintains the hoop-like shape of the muscles around the abdominal cavity, thus preventing their shortening and collapse towards the abdominal cavity which could impair their ability to contract (21).

Impairment of the trunk stabilization

Low back pain (LBP) is one of the most common reasons for seeing a health care provider (26). This is also often the cause of inability to work, as it mainly affects individuals of working age (26,27). Deficits in the lumbar spine stabilization are mostly of muscular or neural origin so the right chosen physical therapy and motor control training that would induce proper co-activation between muscles is recommended (28–30).

Poor postural muscle coordination and deficiency in its stabilizing function is considered to be an important etiological factor in spinal disorders associated with back pain such as deformed spondyloarthritis, intervertebral disc protrusion or spondylolisthesis (19,28,31). The results of studies confirm that abnormalities in motor control may be not only the cause of LBP but also its consequence (32,33). The dependence between the disorder of postural control and the delay in the reaction time of the trunk muscles is a prerequisite for the development of pathology in the lumbar spine. This disorder can be a significant risk factor for lumbar spine injuries (34).

Based on the research results stated above, in clinical practice it appears to be important to evaluate the quality of postural stabilization, to measure IAP and to objectivize individual's ability to regulate the IAP in response to postural load. However, the methods of objective postural trunk assessment and especially of IAP evaluation in relation to postural stabilization are still not unequivocally defined and routinely used. This paper further summarizes currently available methods to evaluate the IAP within clinical assessment.

IAP evaluation

If IAP corresponds with postural stability (4,19,35), we can evaluate postural stability by assessing the IAP. There are various methods of

IAP evaluation with its pros and cons. IAP measurement can be divided into direct and indirect methods. Invasive measurement of the IAP can be done using the caval catheter or transperitoneal measurement during laparoscopic operation. Indirect measurement of IAP can be done using gastric/anorectal/vesical or vaginal probe. The common disadvantage of such IAP evaluation methods is that it is invasive and uncomfortable for the subject. On the other hand, it is the most accurate way of assessing the IAP (37,38).

A. Transperitoneal measurement

This method of direct IAP evaluation is the most accurate (36). In clinical applications it is used for peritoneal dialysis or continuous paracentesis. In the research field it is considered the gold standard for comparison with other invasive methods in case of evaluating IAP. However, it is not used in the rehabilitation and musculoskeletal research and practice because of its invasiveness (37,38).

B. Intracaval measurement

Another example of direct IAP measuring is intracaval measurement. The catheter is inserted via femoral vein to inferior vena cava. The position of the catheter is monitored by ultrasound or x-ray. This procedure is time consuming but allows continuous and accurate results. Disadvantage of this method is possibility of circulatory system infection, bleeding or thrombosis (39).

C. Intravesical measurement

Intravesical measurement is the most common and the most reliable indirect method of monitoring intra-abdominal hypertension (39). This method is recognized as the gold standard for monitoring intra-abdominal compartment syndrome. It may be advantageous way of IAP monitoring in patients having an intravesical catheter because of urinary drainage (39). This method is based on the fact that the urinary bladder can transduce IAP. The measuring itself is done in laying supine position (38).

D. Intravaginal measurement

In this method the pressure sensor is situated in the vagina. Advantage of this method is that wireless sensors can be used, so the IAP can be evaluated during everyday activities (40,41). Disadvantage is that it can only be used in women.

E. Intrarectal measurement

Another method is performed via the rectum. Advantage of this method is that the patient can move and do some physical activities, while the IAP is measured (42). According to Dolan et al., 20% of women refuse to undergo this examination because of fear and they prefer intravaginal measuring (43). Contraindications for examination are bleeding from lower gastrointestinal tract or diarrhea (38).

F. Intragastric measurement

The last option of indirect IAP measuring is a naso/orogastric or gastrostomy probe. Gastric measurement is not used in daily praxis because the patients report it as very uncomfortable. Moreover, it is more expensive compared to intravesical measurement. The other disadvantage of gastric measurement is that the IAP can be influenced by stomach contractions, which occur every 90 minutes lasting about 2 minutes (44). Advantage of this approach is that the IAP can be recorded continuously and can be measured during natural movements such as walking or running (45).

In conclusion, because of its invasiveness these methods are used more for evaluating IAP hypertension, compartment syndrome and for research, then in clinical care.

Trunk muscle activity evaluation

A. Electromyography (EMG)

A standard testing method for muscle activation is EMG. It can be assessed either by non-invasive surface EMG or invasive needle EMG.

Disadvantage to both is that they evaluate more local muscle changes versus coordination of all trunk muscles. Surface EMG cannot be used to assess deep spinal stabilizing muscles. EMG is used more in research than in clinical care (46).

B. Ultrasonography (US) evaluation

Trunk muscle activation can be assessed by real time US to measure the thickness of abdominal or spinal muscles. This method is non-invasive and quite inexpensive, but its reliability is dependent on the experience of the examiner. Compared to EMG, US evaluation can be utilized to assess the deep muscles (47). Similarly to EMG ultrasound provides information about local muscle contraction rather than global muscle coordination.

C. Dynamometry

Dynamometry represents another method to evaluate trunk muscle activation. This non-invasive method measures external forces produced by abdominal wall expansion. Malatova et al. described a tool which consists of four sensors attached to the human body (48). Similar method was introduced by van Ramshorst et al. who correlated IAP with abdominal wall tension. Ramshorst et al. used a special dynamometer to monitor abdominal wall tension resulting from IAP changes in corpses, in which the IAP was changed artificially by insufflation. This study reports that abdominal wall tension reflects the IAP (49).

D. Pressure biofeedback unit

Another possibility of evaluating trunk muscle activation is pressure biofeedback unit. It is basically a tool made from three air chambers and pressure sensors that is placed under the patient. Disadvantage of this method is that activation of the trunk muscles can be evaluated only in certain positions such as lying down. This method of assessment is not useful in dynamic evaluation in difficult postural positions (50).

E. OhmTrak sensor

A non-invasive measurement of the force production of the abdominal wall are sensors inserted in belt such as Ohmbelt device with the OhmTrak sensor (Ohm Belt, Nilus Medical LLC, 2019 © OHMBELT, Redwood City, CA, USA). It is a core activation and breathing tracker. A research version of the device was designed by the manufacturer for the trial purposes, which differs from the commercial version operating with one sensor. The research version utilizes two sensors recording data simultaneously with a software app to display and record both sensor force data. It consists of two capacitive force sensors of 15 mm diameter, 0.35 mm thickness, full scale range 0.45 kg, minimal detectable force 0.9 g, attached to the abdominal wall by adjustable straps. The force sensor which faces the subject's skin, is pressed against the abdominal wall by an adjustable strap. Abdominal wall expansion and retraction is recorded by the sensor as a force. The sensors register the force exerted by the abdominal wall during respiration and various postural tasks. The research version of Ohmbelt allows to monitor simultaneously the instantaneous muscle force at two different trunk locations. Both the amount of the force and its dynamics over time can be analyzed. The sensors are also equipped with accelerometers to capture any kyphotic trunk synkinesis, i.e. substitutive trunk movement replacing abdominal muscle activation. A built-in tensometric transducer converts the force to the digital signal that is transmitted wirelessly via Bluetooth to the computer where the software graphically displays the results. The program records any time sequences with the numerical values being automatically exported into Microsoft Excel. Immediate data analysis, graphical imaging and data saving is available (51).

F. Dynamic Neuromuscular Stabilization (DNS) Brace

DNS Brace device (Produced by Ortotika, FN Motol V Úvalu 84, Praha) is a trunk orthosis equipped with four sensors working on a mechanical-pneumatic-electronic principle. The brace can be fixed firmly to the trunk while not preventing the expansion of soft tissues.

Four mechanical-pneumatic-electronic sensors are placed on the inner wall of plastic trunk orthosis. Two ventral sensors are located bilaterally above the groin and two sensors are located on the brace parts adhering to latero-dorsal sections of the abdominal wall specifically the trigonum lumbale superius. The sensors consist of an air chamber, which detects changes in hydraulic pressure when the sensor is deformed. This chamber is connected by a capillary silicone tube to a digital pressure sensor. As the abdominal wall expands, the IAP increases, which is monitored through the pressure sensor and the pressure value is transmitted via a tube to the digital sensor. The brace sensors measure the pressure exerted by the abdominal wall in kilopascals (kPa) and transfer the data via Bluetooth to a smart-phone or computer so the data can be statistically processed and graphically displayed (52).

G. Clinical tests

The most common and used approach for trunk muscle activation assessment is subjective evaluation using clinical tests (53). Clinicians use their fingers to palpate the quality and symmetry of abdominal wall during client's activation. Further description of clinical tests can be found elsewhere (52,54,55).

Suggestions for clinical practice

80% of western population will experience a LBP at some time during their lives (56). To treat LBP properly and to achieve long lasting results it is necessary to measure trunk stabilization objectively. Evidence based data will help to set up optimal treatment plan, to review the therapy results, to evaluate self-treatment effect and to compare various methods of treatment. Monitoring and training postural stabilization also plays an important role in athletic population to treat and prevent repetitive strain back pain and to promote sports performance (57–59). Since human posture is dynamic, we need a tool to measure IAP and trunk muscle stabilization function in various postural situations. We need to combine clinical assessment with objective measurement. One way to do it, is to use core activation trackers such as Ohmbelt, DNS Brace and alike during dynamic clinical testing. Sensors attached to trunk can inform us objectively about trunk stabilization function and IAP regulation since the IAP correlates with the abdominal wall tension monitored by the sensors (60,61). Body position has significant effects on abdominal wall tension thus also IAP (62). Bellow we present a short case study of a patient with LBP demonstrating how a core tracker device specifically the DNS Brace can be used in an athlete to evaluate and train postural stabilization.

CASE REPORT

An 18-year-old male, competitive canoeist, training 5 times a week 4 hours a day (2 hours rowing, 2 hours gym work) presented with acute low back pain, radiating in L5 nerve root projection to his left leg and thumb. He reported 5/10 intensity of pain on visual analogue scale (VAS). During the preparation for a championship canoeing event, the patient could no longer straighten up after training. Magnetic resonance imaging (MRI) revealed narrowing of the spinal canal at the level of a broadly mediodorsally arched disc L4/5 (3 mm), small dorsal osteophytes L4-S1 and hypertrophic intervertebral joints L4-S1 bilaterally due to spondylarthrosis.

Clinical examination consisted of three tests according to DNS examination protocol, i.e. resting breathing, loaded breathing and the diaphragm test (52,54). All three tests showed that the patient was not able to sufficiently activate the dorsolateral parts of the abdominal wall, lacked lateral expansion of the lower part of the thorax, there was cranial migration of the ribs and the thoracic spine became kyphotic during DNS testing. At the same time, there was excessive activity of the upper part of the rectus abdominis muscle, cranial migration of the umbilicus, concavities of the abdominal wall above the inguinal canal and there was shoulder protraction. Clinically, these are the signs of compromised core stabilization and poor IAP regulation (54,63–65). When analyzing the patient's sport training stereotypes, the same abnormal patterns as in DNS testing were identified including insufficient uprighting of the lumbar and thoracic spine, lack of rotation at the thoracic spine, protraction of the head and shoulders along with de-centration of the shoulder blades. Such signs of suboptimal postural stabilization were present also in sitting positions which is a basic position for canoeing. For objective assessment DNS Brace measurement were performed to analyze abdominal wall activity during resting breathing, diaphragm testing and loaded breathing (51,52)(see Fig. 1,2, and 3 and Table 1).

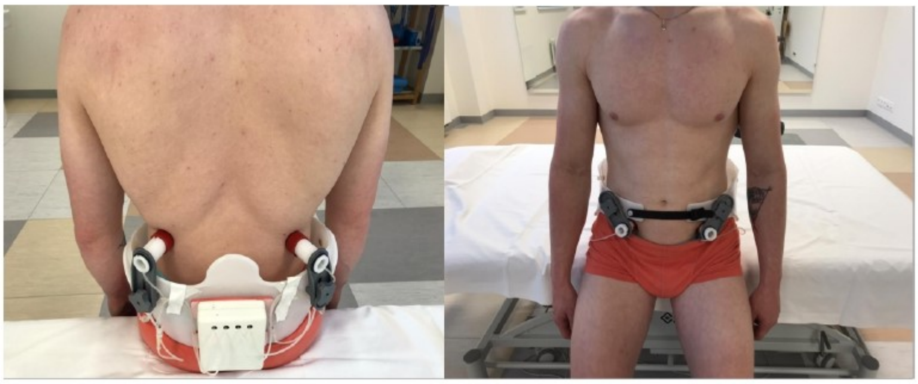
The patient underwent 12 individual therapies provided by an experienced physiotherapist. During each 60 minutes physiotherapy session soft tissue and mobilization techniques were first applied to treat trigger points and joint blockages in thoracic and lumbopelvic area. Following this, the main part of the therapy focused on trunk stabilization training utilizing DNS principles (63–65). Another goal was to train isolated movement in the hip and shoulder joints while maintaining optimal core stabilization and correct sitting position. During the first few physiotherapy sessions mostly static DNS developmental positions were trained (63–65). Later the training focused on dynamic variants of the DNS development exercises. At the end of the 3 months rehabilitation period load was added to the exercises. The patient was advised to perform DNS self-treatment daily and to integrate principles of DNS to sport training.

The clinical assessment after the therapy revealed improvement. In all three tests, resting breathing, loaded breathing and the diaphragm test, patient's lower chest aperture expanded proportionally in all directions during inhalation, the intercostal spaces expanded appropriately and the patient was able to keep the spine upright during the entire tests. Balanced activation of all portions of the abdominal wall was observed and the ability to keep the chest in a neutral position was established. In the sitting position typical for canoeing, there was a noticeable adjustment in trunk stabilization, straightening of the thoracic and lumbar spine as well as proportional activation of all sections of the abdominal wall. Stability of the trunk allowed for improved optimal functional stereotypes of the upper limbs. At the end of the 3 months therapeutic intervention, the patient reported a VAS score of 1/10.

DNS Brace measurements

To monitor abdominal wall tension, a DNS Brace (52) was utilized. This was chosen specifically over other approaches because it allows non-invasive assessment with simultaneous recording from four sensors. It is safe, easy and fast method providing the most comprehensive information about the abdominal wall activity.

Figure 1 Initial position of the patient with DNS Brace before measurement



The following measured scenarios were taken with the patient sitting (Figure 1):

1) Resting breathing: The participant was breathing naturally
2) Loaded breathing: The participant held a load of 20 % of his body weight in hands in front of the trunk
3) Diaphragm test: The participant was expanding the abdominal wall pushing as much as possible against all four sensors attached to DNS Brace (two sensors located above inguinal ligament, two sensors in upper lumbar triangle bilaterally) both during inhalation and exhalation (54)

Fig 2-4 and Table 1 depict abdominal wall activity measured before and after the therapy. An improvement was identified in all three DNS Brace tests after the 3 months treatment period.

Figure 2 Resting breathing - comparison of DNS brace values before and after intervention

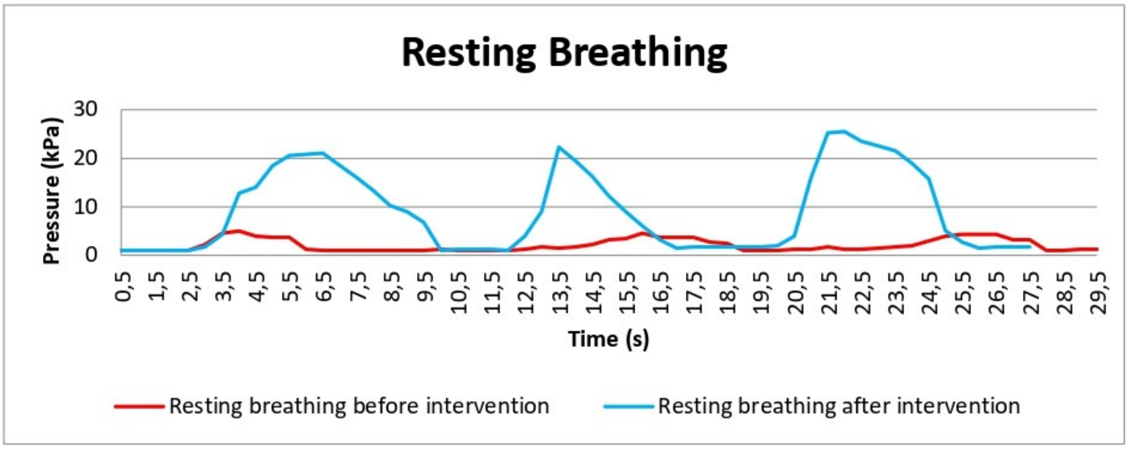


Figure 3 Loaded breathing - comparison of DNS brace values before and after intervention

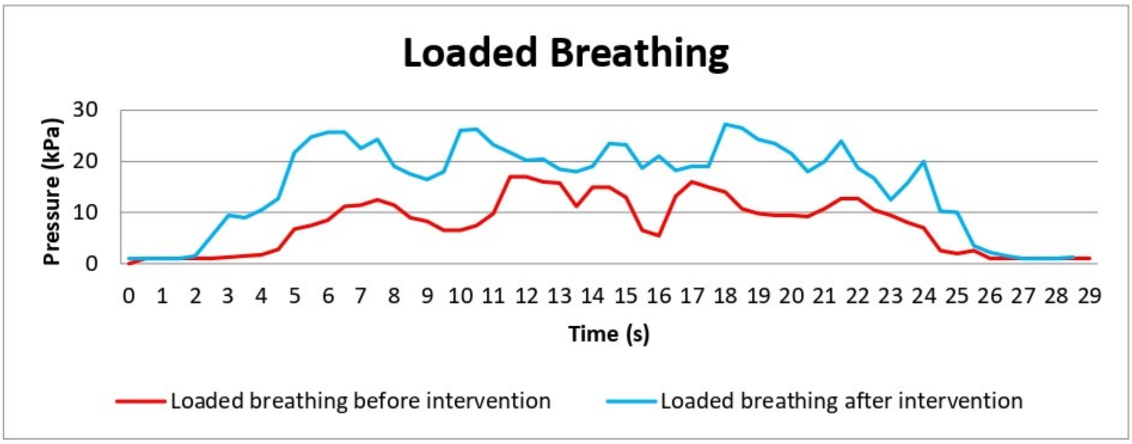


Figure 4 Diaphragm test - comparison of DNS brace values before and after intervention

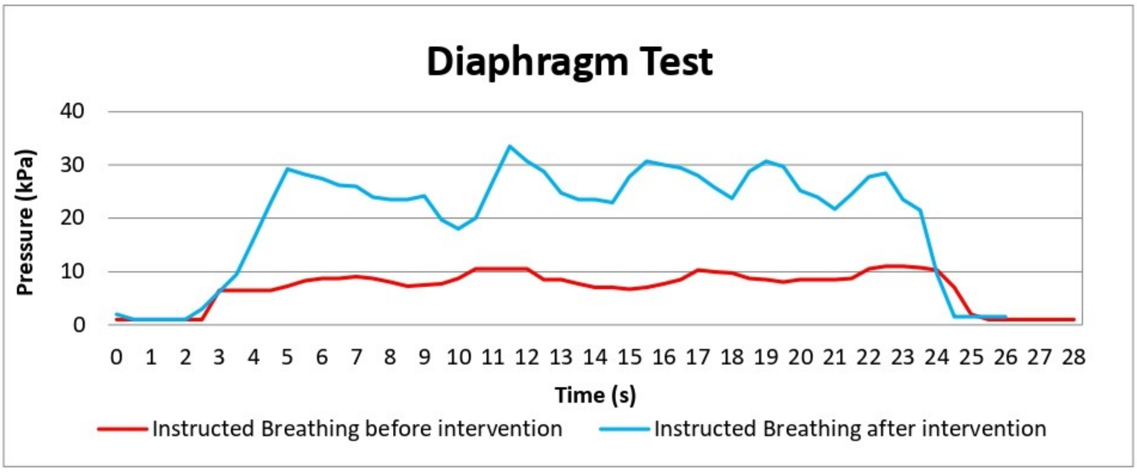


Table 1 DNS assessment protocol and DNS Brace measurement results

SCENARIO	**RESTING BREATHING**		**LOADED BREATHING**		**DIAPHRAGM TEST**	
	DNS assessment protocol (16 points max)	DNS Brace Average value (kPa)	DNS assessment protocol (28 points max)	DNS Brace Average value (kPa)	DNS assessment protocol (28 points max)	DNS Brace Average value (kPa)
Before intervention	6	2,28	13	11,06	11	8,13
After intervention	14	10,09	24	21,02	24	26,42
Difference	+57,2%	+ 79,1%	+45,8%	+ 47,4%	54,2%	+ 69,23%

Note: Clinical assessment performed according to DNS Assessment protocol (54): Breathing stereotype: 16 points = optimal stereotype; Loaded breathing and Diaphragm test: 28 points = optimal stereotype. The smaller the number the worse the stereotype (54).

DNS Brace: the values are given as the average of all 4 sensors

DISCUSSION

After the 3 months therapeutic intervention focusing on trunk stabilization training the patient became almost painless and was able to return to full training regime and competition. The critical part of rehabilitation was integration of proper postural stabilization in sports training to prevent repetitive overstrain of the musculoskeletal system. The positive effect of DNS training on the reduction of pain and the enhancement of sport performance has been previously demonstrated by Davidek et al (66). Six weeks DNS training resulted in significant increase of paddling force measured at kayak ergometer and in reduced pain when moving the arms above the head which is an important aspect in paddling (66). DNS exercises targeting trunk stabilization and segmental movement in the mid-thoracic spine also proved to be effective in the population of competitive cross-country skiers by decreasing back pain and improving sensory perception in thoracic region (67). The positive effect of DNS stabilization strategies on race walker performances has been proven by Panse et al (68). Jebavy et al. report that stabilization-oriented exercises prevent injury and overloading in elite futsal players (69). Jebavy (69) used the same DNS tests for deep stabilization system assessment, however, they evaluated the stabilization function only subjectively on a five-point scale using modified DNS examination protocols (54) without any additional objective measurement. Our case report combined clinical DNS assessments with objective measurements of abdominal wall tension using a DNS Brace.

The main goal of the canoeist's DNS treatment and training was to straighten the lumbar spine, practice segmental rotation in the thoracic spine segments and stabilize the pelvis when moving the upper limbs. Such movements form the basic paddling stereotypes. Similar strategy previously proved to be effective in training of other contralateral sport locomotion stereotypes such as flat water kayaking (66), cross country skiing (67) or futsal. (69) At the end of the therapy the patient was able to practice DNS positions with good quality as defined by DNS assessment protocols (54) as well as in the gym and on the rowing machine. Both clinical and DNS Brace measurements before therapy illustrate almost no expansion of the abdominal wall during resting inhalation. The red curve in the Figure 2 shows only a minimal increase in IAP during inspiration relative to resting expiration baseline. This is related to clinical observation that the patient elevated his chest during inspiration, i.e. used accessory respiratory muscles especially sternocleidomastoid and scalenes to assist in the rib cage elevation, instead of primary inspiratory muscles such as the diaphragm and external intercostal muscles. The post-treatment blue curve depicts much larger inspiratory wave which reflected in clinical assessment as abdominal wall expansion. At the end of quiet exhalation, the curve returns to the baseline, which we consider to be normal since at the end of quiet expiration the IAP value should be minimal (70). Based on DNS Brace and clinical assessment, it can be concluded that after the therapy, the respiratory function of the diaphragm and trunk muscle coordination were optimized.

The aim of the second measurement (Figure 3) was to verify how the patient reflexively reacts to holding a load and whether he uses IAP to stabilize the core during the postural challenging situation. Comparing to the red curve before the therapy, the blue post-treatment curve reflects more intensive activation of the abdominal wall both during inhalation and exhalation indicating higher IAP and better stabilization throughout the movement and more appropriate dual respiratory and postural function of the diaphragm. IAP increase during weight holding (31,35,61) is a critical mechanism of spinal stabilization and protection from injury and should be noted both clinically and by objective measurements.

The third test is called the diaphragm test (Figure 4). It serves to evaluate a patient's voluntary ability to engage the abdominal muscles with proper coactivation of the diaphragm and pelvic floor (54). During clinical assessment the individual is instructed to inhale and push actively against clinician's fingers palpating the latero-dorsal sections of the abdominal wall. With the DNS Brace he activates the abdominal wall against all four sensors placed in the upper lumbar triangle and above the inguinal ligament bilaterally. Prior to therapy, the patient could exert only very little force indicating an incorrect respiratory-stabilization pattern. After the DNS training period a similar increase in abdominal wall activation is observed as in the previous scenario of loaded breathing.

CONCLUSION

This paper summarizes available methods of intra-abdominal pressure assessment and indirect measurements of trunk stabilization. The competitive canoeist case report demonstrates positive results of postural DNS training confirmed by clinical testing, objective DNS Brace measurements and subjective pain perception reported in VAS. This case report methodology may serve as a pilot study for future larger randomized blinded studies where the complete DNS examination protocol (54) could possibly be used to analyze postural stabilization in full detail.

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Declaration of interest
The authors declare that they have no conflict of interest

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6.5. Anorectal dysfunction in multiple sclerosis patients: A pilot study on the effect of an individualized rehabilitation approach.

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Anorectal dysfunction in multiple sclerosis patients: A pilot study on the effect of an individualized rehabilitation approach

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Abstract.
BACKGROUND: Anorectal dysfunction (ARD), especially bowel incontinence, frequently compromises the quality of life in multiple sclerosis (MS) patients. The effect of rehabilitation procedures has not been clearly established.
OBJECTIVE: To determine the effect of an individualized rehabilitation approach on bowel incontinence and anorectal pressures.
METHODS: MS patients with ARD underwent 6-months of individually targeted biofeedback rehabilitation. High resolution anorectal manometry (HRAM) and St. Mark's Fecal Incontinence Scores (SMIS) were completed prior to rehabilitation, after 10 weeks of supervised physiotherapy, and after 3 months of self-treatment.
RESULTS: Ten patients (50%) completed the study. Repeated measures analysis of variance (ANOVA) demonstrated significant improvement in the SMIS questionnaire over time [14.00 baseline vs. 9.70 after supervised physiotherapy vs. 9.30 after self-treatment ($p = 0.005$)]. No significant improvements over time were noted in any HRAM readings: maximal pressure [49.85 mmHg baseline vs. 57.60 after supervised physiotherapy vs. 60.88 after self-treatment ($p = 0.58$)], pressure endurance [36.41 vs. 46.89 vs. 49.95 ($p = 0.53$)], resting pressure [55.83, vs 52.69 vs. 51.84 ($p = 0.704$)], or area under the curve [230.0 vs. 520.8 vs. 501.9 ($p = 0.16$)].
CONCLUSIONS: The proposed individualized rehabilitation program supports a positive overall effect on anorectal dysfunction in MS patients.

Keywords: Multiple sclerosis, bowel incontinence, high resolution anorectal manometry, St. Mark's fecal incontinence score, biofeedback

1. Introduction

Multiple sclerosis (MS) is one of the most common neurological diseases affecting pelvic floor (PF) and gastrointestinal tract function including defecation (Krogh & Christensen, 2009; Nusrat et al., 2012; Preziosi & Emmanuel, 2009). Anorectal dysfunction (ARD) resulting from gastrointestinal autonomic

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disturbance is a frequent symptom in the multiple sclerosis population (Pinter et al., 2015). Compromised coordination of the anorectal musculature may cause many symptoms such as difficult defecation, incontinence, pelvic organs prolapse and pelvic or perianal pain during defecation. These symptoms can occur both separately, and in various combinations (Preziosi & Emmanuel, 2009).

The incidence of ARD symptoms are broad, ranging from 48 % (Munteis et al., 2006) to 68 % (Hinds et al., 1990), which is perhaps due to a lack of patient reporting, or specific questioning by clinicians. These symptoms tend to increase with age, disease duration, coincidence of urinary dysfunctions, and progressing disability score (Munteis et al., 2006). Females seem to be more frequently affected, especially during menopause hormonal changes, or due to episiotomy or labor trauma. ARD is more common in the primary progressive form of MS (Pinter et al., 2015). The prevalence of ARD is higher with progressive worsening of functional status, however, it can occur at any stage of the disease (Nusrat et al., 2012; Preziosi & Emmanuel, 2009). MS patients experience constipation in 18–43%, and stool incontinence in 3–51% (Nusrat et al., 2012) with both symptoms often coexisting (Wiesel, 2000). Coincidence of ARD with urinary dysfunction is also frequently reported (Chia et al., 1995).

Pathophysiology of ARD in MS patients is quite complex, since MS may impair stool continence and defecation at all levels of central nervous processing. Stool incontinence may result from abnormal peristalsis, anorectal hyposensitivity, anal sphincter weakness, prolonged rectoanal inhibitory reflex, impaired rectal compliance or loss of voluntary control of defecation (Preziosi & Emmanuel, 2009). Constipation is even more multifactorial with prolonged colonic transit, abdominal wall weakness, anorectal hyposensitivity, PF dyssynergia, poor diet and behavioral factors such as previous episodes of fecal incontinence and problem to access the toilet playing the role (Preziosi & Emmanuel, 2009). Overflow incontinence is associated with long-term constipation, when sebum is formed in the rectum, resulting in liquid stool and fluid leaks (Lensch & Jost, 2011). MS patients often report limited movement activities (Motl et al., 2017). Lack of movement adversely affects muscle function, including the PF muscles. Patients further reduce mobility to prevent stool and urine leakage out of the house. Hypomobility is related to obesity a reduced muscle power. Thus, the vicious circle is formed. The clinical picture of the ARD is variable. The symptoms can combine, progress and change. Both the constipation and the stool incontinence have negative impact on patient's quality of life (Nusrat et al., 2012).

ARD needs to be assessed and treated comprehensively including physiotherapeutic intervention addressing PF dysfunction (Ruiz & Kaiser, 2017). Conservative treatment affecting behavioral aspects, adequate diet and fluid intake, biofeedback and defecation reflex training as well as regular physical activity are reported to be beneficial (Bywater & While, 2006; Preziosi et al., 2018). Despite the high prevalence of ARD in MS, exact treatment guidelines are still not available. The treatment is mostly empirical and individually tailored based on patient's actual symptoms and treatment preferences (Preziosi et al., 2018). Physiotherapy trains the awareness of the PF muscles, the selective contraction and relaxation of the anal sphincter and PF (Bols et al., 2007) aiming to restore adequate tone and coordination of the PF musculature (Ruiz & Kaiser, 2017), and to improve sensitivity of the rectum (Pedraza et al., 2014). Endurance training may help to reduce bowel urgency and the number of incontinence episodes (Pedraza et al., 2014). The problem needs to be explained to the patient in detail. Description of the basic pelvic anatomy, therapeutic goals and time needed for the training to achieve the goals may help to motivate the patient (Pedraza et al., 2014). Cognitive deficit prevents effective physiotherapy (Beer et al., 2012).

Both, subjective and objective assessment is necessary to set up optimal treatment strategy. Various scores and subjective questionnaires evaluating the quality of life of patients with incontinence and the incontinence itself, and scoring its severity are available. The questionnaires also serve as a feedback to evaluate the therapeutic results. For the purposes of this study, the St. Mark 's Faecal Incontinence Score questionnaire was used (Maeda et al., 2008). High resolution anorectal manometry (HRAM) measures the anorectal resting and squeeze pressure, squeeze endurance and propulsive force (Gosling et al., 2019; Lee & Bharucha, 2016). In MS patients impaired pelvic floor coordination (Marola et al., 2016), decreased anal pressure at rest and reduced maximum sphincter pressure often occurs (Munteis et al., 2008; Nordenbo et al., 1996; Waldron et al., 1993). According to Munteis et al. the maximum sphincter pressure is more reduced in patients with more severe disability and primary progressive form of MS (Munteis et al., 2008).

Table 1
Participants' anthropometric characteristics. $n = 10$, all females

	Age (years)	Height (cm)	Weight (kg)	BMI	EDSS
Mean	47.15	169.07	73.46	25.52	3.65
SD	11	8.09	14.7	3.43	1.55
Min	27	156	55	19.3	2
Max	62	188	109	30.84	6.5

Note: SD = Standard deviation, BMI = body mass index, EDSS = Expanded disability status scale.

The aim of this study was to analyze HRAM findings in MS patients with ARD, specifically stool incontinence, and to evaluate the effect of individual physiotherapy and self-treatment with biofeedback on stool incontinence episodes, anal sphincter function and the quality of life.

2. Materials and methods

2.1. Participants

Initially, 20 patients (3 males, 17 females) with various types of relapsing-remitting, primary or secondary progressive (RS) reporting unwanted leakage of stool at least once a month were recruited to the study. Only 10 female patients completed the entire study, due to various reasons. Three patients reported low self-treatment compliance, and their third assessment was not performed. Two patients did not finish because they suffered MS relapse resulting in inability to perform regular self-treatment. One patient encountered concurrent infectious disease during the study period. Two patients found HRAM uncomfortable and refused to undergo the HRAM repeatedly, and two patients found regular treatment too challenging and did not follow the prescribed exercise protocol. Written informed consent was obtained from each participant, and demographic characteristics of the sample including gender, age, weight height and MS stage measured by Expanded Disability Status Scale (EDSS) are shown in Table 1. The study conforms with The Code of Ethics of the World Medical Association and was approved by the Institutional Ethical Board of University Hospital Motol, Prague, Czech Republic on 17 June 2020.

2.2. Procedures

First, all patients completed a standardized St Marks Incontinence Score (SMIS) questionnaire and underwent HRAM. Anal sphincter pressure at rest, maximal pressure increment and endurance were measured. Then, they received individual physiotherapy from the same skilled physiotherapists 1 time per week, 10 times in total. Patients were advised to perform self-treatment at least 4 times per week reporting the length and frequency of self-treatment in a diary. After the 10 weeks HRAM and SMIS were performed again. Subsequently, the patients underwent three months self-treatment period reporting the exercise in the diary and the final HRAM and SMIS were recorded once more after the 3 months self-treatment period.

2.3. Assessment methods

2.3.1. High resolution anorectal manometry (HRAM)

HRAM was performed using GI Solar system (Medical Measurement Systems = MMS) by the same skilled gastroenterologist with more than 10 years HRAM experience. Before the examination itself, the patient needs to be emptied. During the assessment the patient was laying on the left side with his legs flexed. Calibrated and lubricated water perfused catheter with 8 circumferential sensor elements was gently inserted into the rectum to a depth of about 6 cm, with the most distal sensor remaining externally thus registering the atmospheric pressure and the most proximal sensor registering the pressures at the depth of the anal canal (Kang et al., 2015; Lee & Bharucha, 2016).

The following 3 variables were measured:

1. **Resting pressure mean** is the average pressure (mmHg) monitored in the anal canal for a period of 20 seconds (Lee & Bharucha, 2016). The subjects were instructed not to perform any PF muscle contractions just to remain relaxed.
2. **Maximal pressure increment:** The subjects were instructed to squeeze and suck in the PF with maximum force and hold. The examiner verbally motivated the subject to perform maximum contraction for a period of 5 seconds. After 30 seconds of relaxation the same measurement was repeated (Carrington et al., 2014). The higher value was used for the statistical analysis. The maximal squeeze increment is calculated as the difference between maximum anal squeeze pressure and anal resting pressure (Noelting et al., 2012).
3. **Maximal squeeze pressure endurance:** The subjects were challenged to maintain the

maximum contraction for a period of 20 seconds. Standard protocols suggest to measure endurance over a period of 30 seconds (Carrington et al., 2014; Scott & Carrington, 2020) but this was too challenging for our MS patients and therefore we reduced this period to 20 seconds. The examiner verbally motivated the patients to maintain maximum contraction informing them when the half of the required time (10 s) had elapsed and then five seconds before the end of the maneuver. For statistical analysis the average pressure from the monitored 20 seconds was used. A numerical value denoted as the **area under the curve**, calculated by the MMS program as the area between the markers indicating the beginning and end of the 20 second contraction, was also used for statistical analysis to evaluate the overall endurance ability.

2.3.2. St. Mark's incontinence score

The subjects completed the St. Mark's incontinence score (SMIS) three times (Maeda et al., 2008). At the start of the study before the first physiotherapy, after the 10 weeks of physiotherapy under the therapist's supervision and at the end of the study, i.e. after another 3 months of self-treatment. SMIS provides the information about the nature of incontinence, patient's need for lifestyle changes, the use of plugs or pads, the ability to delay defecation and the need to take any antidiarrheal medication (Norderval et al., 2019; Vaizey et al., 1999). SMIS is sensitive to subjective changes in ARD regardless the type of incontinence, age or sex of the patient (Maeda et al., 2008), and has been shown to be positively correlated with quality of life measures in patients experiencing incontinence (Roos et al., 2009).

2.4. Rehabilitation procedures

All participants patients underwent 10 individual therapies provided by an experienced physiotherapist. During each 60 minutes physiotherapy session soft tissue and mobilization techniques in the lumbopelvic area were applied to treat trigger points and joint blockages (Pedraza et al., 2014). Visceral therapy to treat any resistances in the abdominal cavity including vaginal and rectal manual treatment of muscle spasms was applied as well as any scar treatment in cases where needed. Assessment according to PERFECT scheme (Laycock & Jerwood, 2001) defined patients with muscle weakness less than 2/5 (manual muscle testing) who received electric PF muscle stimulation once a week, i.e. 10 times in total using Enraf – Nonius, Myomed 632 X device. Other patients used biofeedback anal probe to train pelvic flor activation. Postural correction was applied by the therapist following Dynamic Neuromuscular Stabilization (DNS) principles and protocols to improve core stability (Frank et al., 2013; Kobesova et al., 2016). All patients were instructed in PF contraction training, executing exercises in supine, sitting and standing postures, along with more challenging situations such as: coughing, squatting, jumping, lifting a load or jogging if able to perform such activities.

The patients were educated about PF anatomy and function. Using the PERFECT scheme (Laycock & Jerwood, 2001) which evaluates PF power, number of squeezes the patient can perform and the endurance, individually tailored self-treatment protocol was defined for each patient consisting of the following parts:

1) Reeducation of the defecation act in patients with the constipation - increased position of lower extremities, voluntary relaxation of the PF with subsequent training of the targeted localized pressure to the rectum and abdominal massage (Cotterill et al., 2018; Khera et al., 2019).
2) Bowel drill/bladder drill – during urgency the individual pulls the PF in and squeezes the sphincters to stop the urgency and avoid the leaks (Booth et al., 2020).
3) Postural training according to DNS approach to achieve optimal trunk stabilization and intra-abdominal pressure regulation (Frank et al., 2013; Kobesova et al., 2016). Training of PF squeeze in DNS exercise positions: supine, prone, sitting, standing, squatting, jumping and when lifting a load.
4) Stretching of hamstrings, adductors and tensor fascia lata muscle. Patients suffering from spasticity preformed progressive stretching for at least 10 minutes daily (Halabchi et al., 2017; Smania et al., 2010), patients with trigger points without spasticity were advised to stretch each group following trigger point treatment manuals (Majlesi & Unalan, 2010; Yumpu.com, n.d.).
5) Patients were advised to perform dynamic physical activity 2-3 times a week and resistance training 2-3 times per week following physical activity guidelines for MS patients (Kim et al., 2019).

Table 2
Comparison of SMIS scores and HRAM readings across supervised physiotherapy and self-treatment sessions. Values are Mean (Standard Deviation)

Measure	Baseline mean (SD)	Post supervised treatment mean (SD)	Post self-treatment mean (SD)	Effect size[c]	*P* value
SMIS	14.00 (4.97)	9.70 (4.88)	9.30 (3.13)	0.449	0.005*
Resting pressure[a]	55.83 (18.93)	52.69 (21.62)	51.84 (16.58)	0.038	0.704
Maximal pressure increment[a]	49.85 (36.71)	57.60 (55.59)	60.88 (46.46)	0.058	0.582
Maximal pressure endurance[a]	36.41 (33.30)	46.89 (44.38)	49.95 (52.81)	0.055	0.529
Area under curve[b]	230.0 (233.6)	520.8 (423.5)	501.9 (532.0)	0.248	0.107

Note: HRAM = High resolution anal manometry. SMIS = St. Marks Incontinence Score. [a]HRAM measures in (mmHg). [b]Area under curve measures in (mmHg/s). [c]Effect size = Partial eta squared (η^2). *Statistically significantly difference observed ($p < 0.05$).

6) Patients were advised to respect exhaustion and prefer shorter exercise sessions (10–15 minutes) several times (2-3 times) a day.

2.5. Statistical analysis

Descriptive statistics were calculated for all variables. Data are mean ± standard deviation, unless otherwise stated. A one-way repeated measures analysis of variance (ANOVA) was used to determine whether there were differences in HRAM readings (resting pressure, maximal pressure increment, maximal pressure endurance) and SMIS scores over three months of supervised physiotherapy and three additional months of self-treatment. There were several outliers in the data, as assessed by boxplots. However, due to the small sample size, outliers were retained in the data; with no appreciable differences comparing results after modifying to larger or smaller than next closest values. Not all data was normally distributed for each time point, as assessed by Shapiro-Wilk's test ($p > .05$), however such data were not transformed, as ANOVAs are robust to non-normality. In data where sphericity was violated, Greenhouse-Geisser corrections were applied. Main effects were run for time, and post-hoc tests were conducted when necessary. Data analyses were conducted with the Statistical Package for the Social Sciences (SPSS version 27.0 for Mac; IMB Corp, Armonk, NY).

3. Results

Ten patients completed the entire study. Descriptive statistics are presented for the participants in Table 1, with all HRAM and SMIS data presented in Table 2. For the SMIS, the main effect of time showed a statistically significant difference

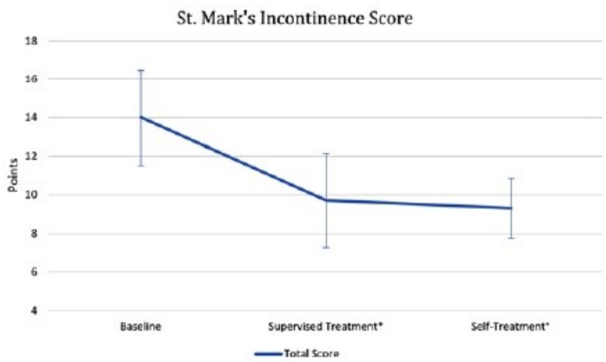

Fig. 1. St. Mark's Incontinence Scores values for all time measurements. *Significant difference observed from baseline, $p < 0.05$.

between time points during the intervention period ($F(2, 18) = 7.32$, $p = 0.005$, partial $\eta^2 = .45$). *Post-hoc* analyses revealed a decrease in SMIS from baseline scores pre-intervention of 14.0 ± 4.97 points to 9.70 ± 4.88 points three months after supervised physiotherapy treatment sessions, a statistically significant decrease of 4.30 (95% CI, 1.27 to 7.33) points, $p = 0.007$, and another decrease in SMIS to 9.30 ± 3.13 points after three additional months of self-treatment, a statistically significant decrease of 4.70 (95% CI, 0.58 to 8.83) points, $p = 0.026$ compared with to baseline. There was no significant difference between the supervised and self-treatment time points (Fig. 1). The observed power, analyzed *post-hoc*, was 0.82 for the SMIS. For the HRAM, there were no statistically significant differences in time for any of the readings including: resting pressures ($F(2, 18) = 0.358$, $p = 0.70$), pressure increment ($F(2, 18) = 0.559$, $p = 0.58$), pressure endurance ($F(1.28, 11.55) = 0.52$, $p = 0.53$), or area under the curve ($F(1.24, 11.18) = 2.97$, $p = 0.16$) (Table 2 and Fig 2).

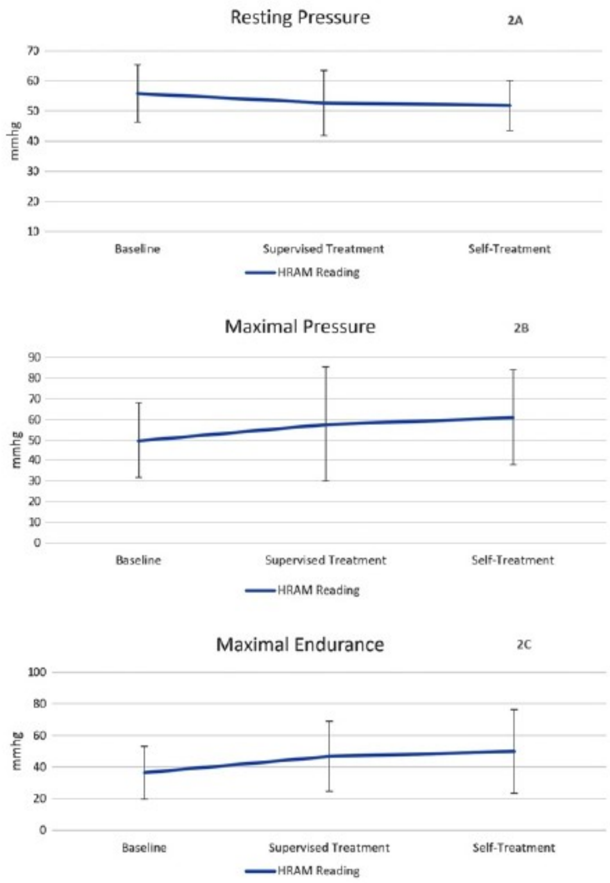

Fig. 2. 2A:Trend in resting pressure, 2B: Trend in maximum pressure, 2C: Trend in endurance increase over the monitored time. No significant differences noted from baseline.

4. Discussion

The results of this study demonstrate some initial benefits from an individualized rehabilitation program in MS patients suffering from ARD. Albeit fecal incontinence is frequent in the MS patient population (Chia et al., 1995; Hinds et al., 1990; Munteis et al., 2006; Pinter et al., 2015; Preziosi & Emmanuel, 2009), this topic is still somewhat taboo (Preziosi et al., 2018) and patients are not adequately investigated and treated. Although half of our patients did not complete the whole study, they were all grateful that we actively asked about this delicate problem and offered targeted examinations, therapy, and advice on how to deal with such personally and socially devastating symptoms. This was also reflected in the subjective evaluation of the 10 patients who completed the study and reported a significant improvement. The effect of physiotherapy and feedback exercise on fecal incontinence of various origin was investigated by Norton et al (Norton & Cody, 2012) who analyzed the results of 21 studies. Although most papers publish uncontrolled studies, ARD symptoms improvement is reported in most of them. Norton concludes, that biofeedback, electrical stimulation and exercise may have a therapeutic effect, however, larger well-designed trials are needed to enable safe conclusions. The therapy effect was well proved in urinary incontinence (Kopańska et al., 2020; Mazur-Bialy et al., 2020; Nightingale, 2020). The PF muscles regulating stool continence and defecation are also involved in the physiological act of micturition, thus the similar exercise effect could be expected in both stool and urinary incontinence (Nusrat et al., 2012). The scientific literature mostly presents ARD functional assessment and treatment procedures in diagnoses other than MS (S. S. C. Rao et al., 2016). Albeit treatment principles may be the same in various types of ARD (S. S. C. Rao et al., 2016) not all types of conservative treatment were tested in MS patients and available studies are largely restricted to small case series (Nusrat et al., 2012; Preziosi et al., 2018). Exercise protocols, behavioral therapy and appropriate diet appears to be beneficial for patients with MS despite the lack of evidence (Nusrat et al., 2012; Preziosi et al., 2011, 2018). There are no precise therapeutic recommendations or guidelines, therefore the empirical treatment based on clinical symptoms and experience is mostly applied (Nusrat et al., 2012; Preziosi et al., 2018).

HRAM parameters measured in our study showed statistically insignificant improvements, likely due to the small sample who completed the study. Nevertheless, these findings are valuable because such research is lacking in the MS population. First, the resting pressure was measured. The normal range of anal pressures is relatively wide and dependent on sex and age, fluctuating between 32 and 88 mmHg (Lee & Bharucha, 2016; Noelting et al., 2012). In our study, the average resting pressure before intervention was 55.8 mmHg decreasing slightly after the period of rehabilitation under the therapist's supervision to 52.7 mmHg while the last measurement after 3 months of self-treatment remained at a similar level (51.8 mmHg). Over 70% of resting anal pressure depends on the tone generated by the internal anal sphincter that is under the autonomic innervation (Keef & Cobine, 2019). So, it is not surprising this variable demonstrated little change with rehabilitation that mainly addressed the skeletal muscle of the external anal sphincter (Fig. 2A). Also, the physiotherapist not only instructed patients how to activate the PF muscles, but relaxation training was another important aspect of rehabilitation. Perhaps the slight decrease in resting pressure resulted from patients' improved ability in relaxing the PF. Hyperactivity in the PF is associated with pelvic pain, urinary urgency, incontinence, defecatory dysfunction, and sexual symptoms; thus the relaxation procedures form an important part of PF rehabilitation (Aw et al., 2017).

The ability to increase anal pressure improved over the observed time period. Initial maximal pressure increment (maximal anal squeeze pressure minus anal resting pressure (Noelting et al., 2012)) of 49.85 mmHg increased to 57.60 on the second measurement and even increased slightly to 60.88 mmHg in the final measurement after 3 months of self-treatment. Such trend (Fig. 2B) is desirable, even though the difference was not great enough to reach statistical significance ($p = 0.582$) and none of the measured values (between 124 ± 56 and 174 ± 81 mmHg) reached the defined norms for healthy populations based on age and gender (Oblizajek et al., 2019). Using the HRM apparatus in our gastroenterology center where this study was performed, 120 mmHg is considered to be normal for both genders, and incontinent patients typically demonstrate lower values (Ramage et al., 2019). The low maximum sphincter pressure in our MS cohort may have resulted from disturbed innervation of the external anal sphincter, however, the effort of the patient can also be a limitation (Lazarescu et al., 2009; Lee & Bharucha, 2016). Therefore, it is necessary to motivate patients during the examination (Heinrich et al., 2013). The compliance and current emotional and cognitive state of our MS patients could also possibly influence the results of the measurements.

The last analyzed maneuver was the squeeze pressure endurance. According to Carrington et al. (Carrington et al., 2014), squeeze endurance has such a wide variation in healthy populations that this parameter is unlikely to be of diagnostic utility. Lee and Bharucha further describe that the clinical significance of low squeeze duration is unknown (Lee & Bharucha, 2016). Additionally, there are variations in how researchers measure squeeze duration, thus recording different norms (Fox et al., 2004; Heinrich et al., 2013; Lee & Bharucha, 2016; Noelting et al., 2012; Oblizajek et al., 2019; S. S. Rao et al., 1999). In our study we verbally motivated patients to maintain maximum contraction for 20 seconds using average pressure from the monitored 20 seconds for statistical analysis. The trend (Fig. 2C) of this parameter over the observed time was increasing but not reaching statistical significance ($p = 0.107$). The endurance squeeze pressure reflects mainly external sphincter function which can be addressed through training (Booth et al., 2020; Preziosi et al., 2011). Reduced endurance typically signifies external sphincter damage or dysfunction and it also describes fatigue (Fox et al., 2004). The endurance of the external anal sphincter is an important factor in maintaining fecal continence (Teng et al., 2018). Finally, for the pressure endurance maneuver we also calculated the area under the squeeze-duration curve, which is an indicator of the contraction endurance and decrease in muscle strength due to fatigue (Fox et al., 2004; Laycock & Jerwood, 2001). From initial 230 mmHg/s this parameter desirably increased to 520.8 mmHg/s after the 3 months of guided intervention and then slightly dropped to 501.9 after another 3 months of self-treatment. The improving trend especially between the first and second measurement, however, have not reached statistical significance.

The only statistically significant improvement was identified in subjective perception of ARD by patients reported in the SMIS. The initial mean score of 14.00 points dropped to 9.70 after the series of supervised rehabilitation and more or less the same score (9.30 points) was reported after another three months of self-treatment. The subjective improvement was noted mainly in decreased incontinence both for solid and liquid stool and in the ability to defer the defection. Extensive research is available on ARD treatment, however, only limited number of studies describe patient's subjective perception of rehabilitation procedures on fecal incontinence in MS population specifically. Preziozi et al. (Preziosi et al., 2011) and Weisel (Wiesel, 2000) report positive effect of biofeedback behavioral therapy in MS patients. Posterior tibial nerve stimulation was identified as possibly effective for fecal incontinence treatment in MS patients (Sanagapalli et al., 2018) as well as sacral nerve stimulation which is discussed in the literature with inconsistent conclusions (Gulick & Namey, 2012; Preziosi et al., 2018; Remmen & Dindo, 2013). As far as exercise and physical activity, Gulick and Namey (Gulick & Namey, 2012) state that structured exercise programs, aerobic training and fitness may bring improvement in bowel functioning, yet also warns how bowel and bladder symptoms may worsen with increased levels of physical activity. Pelvic floor muscle training combined with biofeedback resulted in subjective improvement of a MS patient with rectal prolapse (Sandalcidi, 2016) but this is only one case report. Still, the Consortium of Multiple Sclerosis

Centers recommends exercise, physical therapy to increase general mobility, and core strengthening to treat bowel dysfunction (Newsome et al., 2017). Since SMIS positively correlates with patients quality of life (Roos et al., 2009) we consider the statistically significant improvement in our cohort to be of critical importance. From patient's perspective this maybe of more importance than any objective changes identified via HRAM.

Our treatment strategy involved patient's education, biofeedback, core stabilization exercises, sphincter contraction control training, stretching and relaxation procedures and manual treatment. While the number, frequency and length of treatment sessions were identical for all the subjects, the program itself, i.e. the combination and the length of various treatment procedures was individually tailored to each patient.

As far as the study limits, we acknowledge the lack of a control group and the small number of participants with only half of initially recruited participants completing the whole study. The MS population divers greatly in terms of clinical symptoms, speed of progression disease fluctuation, and the level of cognitive function which is decisive for rehabilitation coping and results. Perhaps, future studies should be done over a shorter period of time on more homogeneous sample of MS patients.

5. Conclusions

This study presents a positive overall effect of targeted physiotherapy programing on anorectal dysfunction in MS patients. Stool incontinence, measured through the SMIS, improved significantly. Despite nonsignificant HRAM results, the trend in data was favorable, with positive subjective perceptions suggesting that MS patients with ARD may benefit from the proposed complex rehabilitation approach. This rehabilitation approach may serve as the groundwork for future randomized controlled trials comparing rehabilitation strategies.

Author contributions

Martina Kovari: Conceptualization, Project administration, Methodology, Investigation, Data curation, Writing - original draft. **Jan Stovicek:** Conceptualization, Methodology, Investigation. **Jakub Novak:** Investigation, Data curation, Writing - review & editing. **Michaela Havlickova:** Project administration, Methodology, Investigation. **Sarka Mala:** Conceptualization, Project administration, Methodology, Investigation. **Andrew Busch:** Data curation, Software, Writing - review & editing. **Pavel Kolar:** Conceptualization. **Alena Kobesova:** Conceptualization, Supervision, Writing - review & editing, Funding acquisition.

Conflict of interest

There are no conflicts of interest to disclose.

Ethical considerations

The study conforms with The Code of Ethics of the World Medical Association and was approved by the Institutional Ethical Board of University Hospital Motol, Prague, Czech Republic on 17 June 2020.

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6.6. How to prepare an optimal design of a clinical study focusing on chronic low back pain: guidelines based on a review of scientific papers published in 2014–2019

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Jak připravit optimální design klinické studie zaměřené na chronické bolesti bederní páteře: doporučení na základě literární rešerše prací publikovaných v letech 2014–2019

How to prepare an optimal design of a clinical study focusing on chronic low back pain: guidelines based on a review of scientific papers published in 2014–2019

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Souhrn: Úvod: Chronické bolesti v bedrech (LBP – low back pain) jsou jednou z nejčastějších diagnóz v současné dospělé populaci, a proto je této problematice věnován extenzivní vědecký výzkum. Design jednotlivých vědeckých studií se ale v mnoha aspektech zásadně liší, což znemožňuje porovnávat výsledky studií mezi sebou. Na základě detailní rešerše recentních prací publikovaných v mezinárodních časopisech s impakt faktorem nabízí tento článek návod, jak správně designovat studie zaměřené na hodnocení efektu terapeutických postupů u LBP. **Metoda:** V databázi PubMed byly vybrány klinické studie publikované v časopisech první poloviny žebříčku impakt faktoru v kategorii Rehabilitation dle Journal Citation Reports, které byly publikovány od března 2014 do června 2019. Hlavním parametrem vyhledávání byl MeSH (Medical Subjects Headings) termín „low back pain". Analyzována byla data o velikosti souboru probandů, inkluzivních a exkluzivních kritériích, definici kontrolní skupiny, designu zkoumané intervence, měřených veličinách a nástrojích měření. **Výsledky:** Do výsledné analýzy bylo zařazeno 66 originálních prací. Medián velikosti souboru probandů byl 72,5. Nejčastěji hodnocenými intervencemi byly cvičební programy (29/66). Nejčastější délka intervence byla 4–8 týdnů (28/66), nejčastější frekvence intervence byla 2× týdně (15/40). Kontrolní skupině bylo poskytnuto menší množství péče než intervenční skupině téměř v polovině případů (25/55). Pro hodnocení efektu intervence bylo nejčastěji použito dotazníkového šetření (65/66). Hodnocení pomocí přístrojových metod (18/66) a klinických testů (11/66) bylo méně časté než hodnocení pacienty (patient reported outcome measures, 65/66). Parametry, které byly hodnoceny dotazníkovými metodami, byly nejčastěji bolest (58/66) a disabilita (58/66). Bolest byla nejčastěji hodnocena pomocí numerické škály intenzity bolesti (28/66) a vizuální analogové škály (22/66). Disabilita nejčastěji pomocí Roland-Morris Disability Questionnaire (28/65) a Oswestry Disability Index (18/65). **Závěr:** Na základě literární rešerše doporučujeme postup, jak optimálně připravit design studií zaměřených na objektivizaci různých typů terapie u pacientů s LBP.

Klíčová slova: bolesti bederní páteře – randomizovaná kontrolovaná studie – design výzkumné studie LBP – doporučené postupy

Summary: Introduction: Chronic low back pain (LBP) is one of the most common diagnoses in the current adult population and has been therefore subject to extensive scientific research. However, the design of individual scientific studies differs fundamentally in many respects, which makes it impossible to compare their results. Based on a detailed research of recent papers published in international journals with impact factor, this article offers guidelines how to appropriately design studies evaluating the effect of therapeutic procedures in LBP. **Method:** Clinical studies published from March 2014 to June 2019 in journals ranked in the first half of the impact factor ranking in the Rehabilitation category according to the Journal Citation Reports were selected in the PubMed database. The main search MeSH (Medical Subjects Headings) parameter was "low back pain". The following data were analysed:: number of participants in the experimental and control group, inclusive and exclusive criteria, definition of the control group, intervention design, measured parameters and measurement tools. **Results:** A total of 66 original works were included in the final analysis. The median number of participants included in a study was 72.5. The most frequently evaluated interventions were exercise programs (29/66). The most common duration of intervention was 4–8 weeks (28/66), the most common frequency of intervention was twice a week (15/40). The control group received less care than the intervention group in almost half of the studies (25/55). A questionnaire survey (65/66) was most often used to evaluate the effect of the intervention. Instrumental evaluating methods (18/66) and clinical tests (11/66) were applied less frequently than patient reported outcome measures (65/66). The parameters that were evaluated by questionnaire methods were most often pain (58/66) and disability (58/66). Pain was most often assessed via numeric pain rating scale (28/66) or visual analogue scale (22/66). Disability was most often evaluated by the Roland-Morris Disability Questionnaire (28/65) and the Oswestry Disability Index (18/65). **Conclusion:** Based on the literature search, this paper recommends procedures to optimally design studies objectifying different types of treatment methods in LBP patients.

Key words: low back pain – randomised controlled trial – LBP research study design – guidelines

Úvod

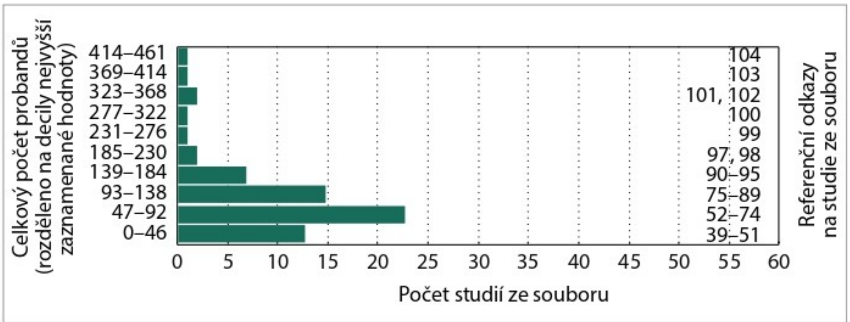
Bolesti bederní páteře (LBP – low back pain) jsou celosvětově nejčastější příčinou disability, a to zejména v ekonomicky vyspělých zemích [1]. Představují zásadní ekonomickou zátěž pro celou společnost, zejména pro zdravotnický a sociální systém [2,3]. Jedná se o jednu z nejčastějších příčin snížené kvality života jednotlivce [4,5]. Předpokladem identifikace efektivních terapeutických postupů LBP v rámci medicíny založené na důkazech je kvalitní metodika výzkumných studií. Zlatým standardem na poli hodnocení účinnosti intervence je randomizovaná kontrolovaná studie (RCT – randomised controlled trial) [6]. Dobře navržené a správně provedené RCT jsou zdrojem nejspolehlivějších důkazů o účinnosti zdravotnické intervence. Naopak studie, ve kterých je používáno nevhodných metod, jsou zdrojem zavádějících tvrzení, bývají spojeny se zaujatostí, zejména s nadhodnocováním léčebného účinku [7]. Přínos RCT závisí na designu, provedení a reportu (popisu průběhu RCT). Kvalitní design a provedení výzkumného projektu jsou předpokladem spolehlivých výsledků. Kvalitní report umožňuje čtenářům posoudit spolehlivost a platnost předkládaných informací [6].

Cílem tohoto článku je přinést přehled nejčastěji používaných metodických postupů, tj. designů RCT na téma LBP. Práce vychází z rešerše prací publikovaných v letech 2014–2019 v mezinárodních časopisech s impakt faktorem, indexovaných v databázi PubMed. Hodnoceny byly tyto parametry: velikost vzorku, inkluzivní a exkluzivní kritéria, design intervenční skupiny, design kontrolní skupiny (KS) a použité měřicí metody.

Metodika

Na základě rešerše bylo shromážděno 66 klinických studií a protokolů ke klinickým studiím. Ve všech byl hodnocen efekt různých typů zdravotnické intervence (fyzioterapeutické postupy, semiinvazivní postupy, např. obstřiky či injekční aplikace hyaluronátu, i postupy operační) u pacientů s diagnózou chronických bolestí bederní páteře (cLBP – chronic LBP). Vyhledávání probíhalo v databázi PubMed. Všechny studie byly publikovány od března 2014 do června 2019 v časopisech, které se nacházely v první polovině žebříčku impakt faktoru dle Journal Citation Reports v kategorii „Rehabilitation". Mezi MeSH termíny bylo uvedeno „low back pain" a ve výběru „All Fields" slovo „chronic". Tři protokoly z původních 69 výsledků byly vyřazeny, protože se jednalo o duplicitní výsledky.

Data byla zpracována pomocí tabulkového editoru, do kterého byly zaznamenány informace o velikosti vzorku probandů, kritériích inkluze a exkluze, designu intervenční skupiny, designu KS a použitých měřicích metodách. Tyto proměnné byly vybrány na základě doporučení Consolidated Standards of Reporting Trials – CONSORT 2010 [6]. Jedná se o seznam nutných částí reportu klinické studie sestavený skupinou editorů, vědců a metodologů. Iniciativa vznikla v reakci na nedostatky v informacích uváděných v popisu klinických studií [6]. Grafy 1–9 s výsledky uvádějí odkazy na konkrétní studie z analyzovaného souboru 66 publikovaných prací.



Graf 1. Studie ze souboru podle počtu zařazených probandů.
Graph 1. Studies from the set according to the number of probands included.
Graf uvádí odkazy na konkrétní studie z analyzovaného souboru 66 publikovaných prací.

Výsledky

Velikost vzorku probandů

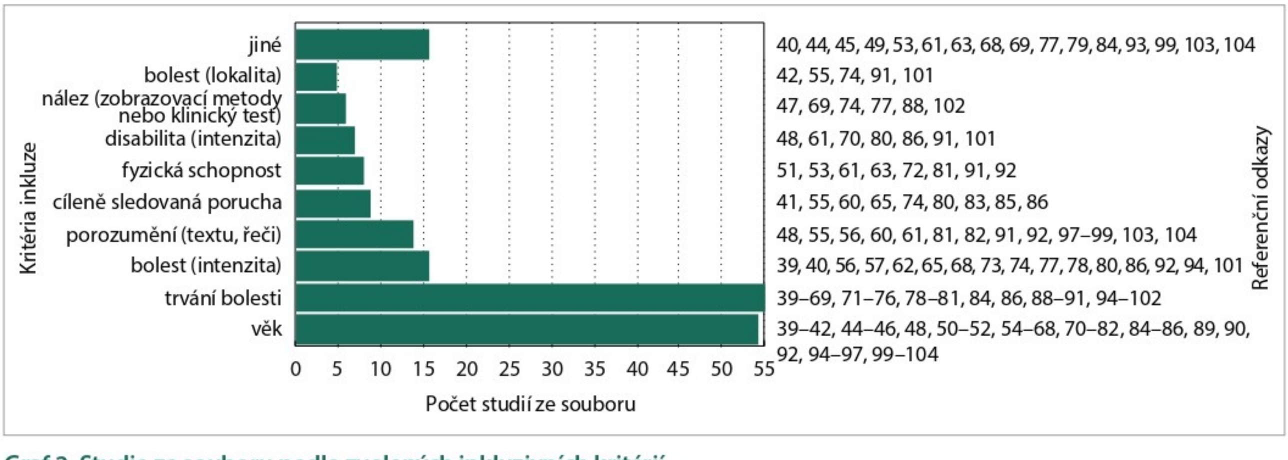
Velikost vzorku probandů odpovídá konečnému počtu měřených subjektů. Dostatečný počet probandů v experimentální i KS je základním předpokladem pro získání statisticky a zároveň klinicky významných výsledků RCT [6]. Zjištěné velikosti vzorku probandů byly rozděleny po decilech nejvyšší pozorované hodnoty. Nejvyšší pozorovaný počet probandů byl 461. Prvnímu decilu odpovídá interval 0–46, druhému decilu 47–92 atd. Přehled výsledků je uveden v grafu 1. V souboru se nacházely pilotní studie a studie proveditelnosti (feasibility) s celkovým počtem probandů rovným 10–40 probandů. Rozsáhlé multicentrické (tj. z více pracovišť) studie zahrnovaly stovky probandů. Medián velikosti vzorku probandů v souboru je 72,5 (70 a 75). Nejvíce studií (23/66) sledovalo 47–92 probandů v rámci kontrolní i intervenční skupiny dohromady (graf 1).

Kritéria inkluze a exkluze

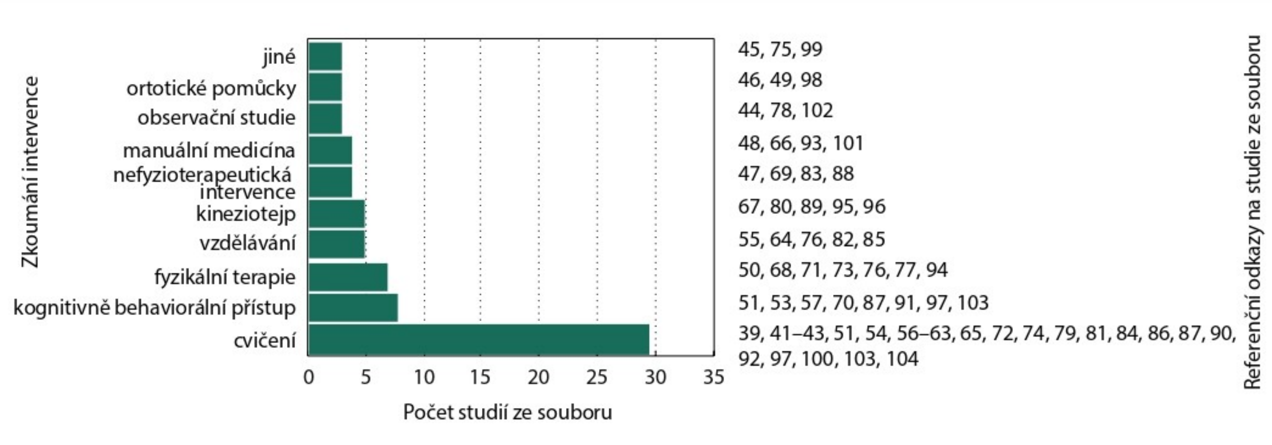
Kritéria inkluze a exkluze jsou nástrojem pro předběžné vymezení cílové populace (target population) [7]. Inkluzivní kritéria definují podmínky pro zařazení probanda do studie (graf 2). Exkluzivní kritéria definují podmínky pro vyřazení probanda. Probandi, kteří splňují kritéria, mohou být považováni za modelový příklad cílové populace. Jejich reakce na intervenci je příkladem reakce cílové populace. Jsou-li ostatní složky designu odpovídající kvality, můžeme na základě pozorování chování populace studie (study population) učinit závěry o chování celé cílové populace ve stejných podmínkách [6,8]. Často definovanými kritérii jsou: věk, diagnóza a stadium onemocnění nebo problému. Mezi nejčastější exkluzivní kritéria patří komorbidity (tj. jiná onemocnění než LBP), které mohou ovlivnit sledované parametry. Vyřazováni jsou též probandi, kteří by pravděpodobně netolerovali testovanou intervenci (např. alergie na lepidlo kineziotejpu apod.) nebo nevyhovují náležitostem zajišťujícím právní a etické zázemí studie – typicky se jedná o porozumění a vyplnění informovaného souhlasu [6].

Tomu odpovídají i výsledky naší rešerše (graf 2). Probandi byli nejčastěji v produktivním věku (18–65 let). Nicméně se objevily i studie cílené na problematiku LBP u starší populace. Stadium nemoci bylo vymezeno akutností, resp. chronicitou (v grafu 2 uvedeno jako „trvání bolesti"). Hranice pro chronicitu byla často uváděna jako přítomnost bolestí nejméně po dobu 3 po sobě následujících měsíců. Objevovaly se však i jiné definice chronické bolesti. Povaha onemocnění byla nejčastěji uváděna jako nespecifická bolest bederní páteře (non-specific LBP). Jedná se o přítomnost bolesti z jiných než známých příčin. O specifickou bolest se naopak jedná, pokud je jasně stanovena příčina LBP v důsledku jiného onemocnění nebo poranění. Mnoho kritérií bylo zaměřeno právě na exkluzi pacientů se známou příčinou LBP nebo s významnou komorbiditou.

Mezi nejčastěji se vyskytující kritéria exkluze patřila plánovaná nebo již uskutečněná operace páteře, břicha nebo dolních končetin, jiná probíhající intervence (vč. masáží, jiných cvičení apod.), významné degenerativní onemocnění páteře nebo nosných kloubů dolních končetin a v neposlední řadě těhotenství. Přibližně v polovině případů byli vyřazováni probandi s výraznými bolestmi v jiné lokalitě na těle (často definované jako bolesti nad úrovní 12. žebra a pod úrovní gluteálních rýh), s příznaky radikulárního dráždění, se strukturálními deformitami páteře nebo dolních končetin, neurologickým deficitem, revmatickými nebo onkologickými onemoc-



Graf 2. Studie ze souboru podle zvolených inkluzivních kritérií.
Graph 2. Studies from the set according to the selected inclusive criteria.
Graf uvádí odkazy na konkrétní studie z analyzovaného souboru 66 publikovaných prací.
Do kategorie „jiné" byly zařazeny všechny výsledky, jejichž četnost výskytu byla < 5, patří sem: pracovní status [49,61,63,79], pohlaví [49,63,84], přístup k technickému vybavení (telefon, televize) [45,99], množství pohybové aktivity [44,53], psychometrické parametry [40,68], kritéria nebyla uvedena [45,93], začíná s rehabilitací [103,104], nezabrala konzervativní terapie [69], nelepší se [79], nespokojenost s fyzickou funkcí [53], body mass index [44], časové možnosti [77].



Graf. 3. Přehled studií ze souboru podle zkoumané intervence.
Graph 3. Overview of studies from the set according to the examined intervention.
Graf uvádí odkazy na konkrétní studie z analyzovaného souboru 66 publikovaných prací.
Do kategorie „jiné" byly zařazeny všechny výsledky, jejichž četnost výskytu byla < 3, patří sem: intervence na terapeutech (např. vzdělávání) [45,99], biofeedback [75].

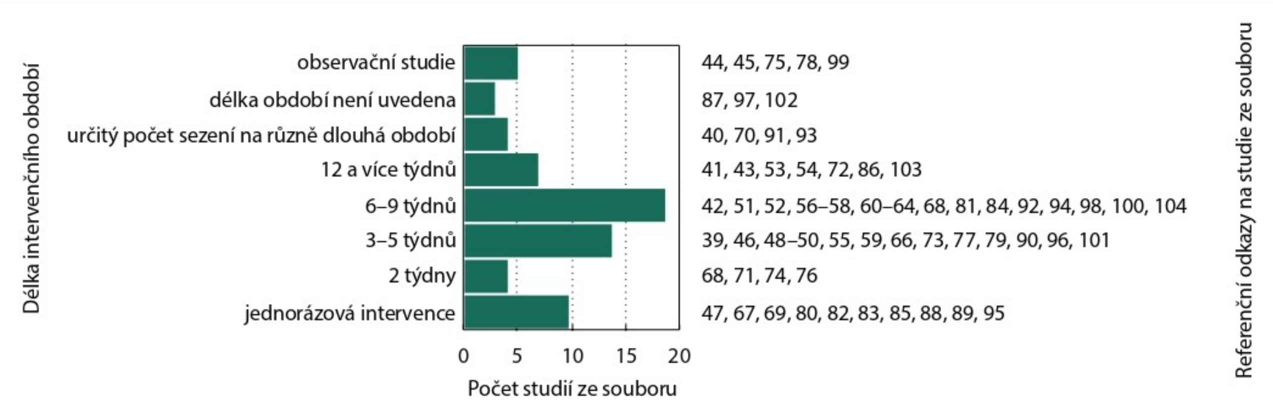
něními a frakturami. Menší část studií věnovala pozornost vyřazení probandů s významnými kardiorespiračními onemocněními, dále probandů, pro které je hodnocená intervence kontraindikována nebo u kterých probíhá akutní infekční onemocnění. V neposlední řadě se vyskytovaly exkluze z důvodu potíží vyžadujících psychologickou nebo psychiatrickou péči, alergie na hodnocenou proceduru, kognitivního deficitu probanda, probíhajícího pojistného řízení pro bolesti zad nebo daná studie vyžadovala určitý pracovní status (pracovní neschopnost, starobní důchod apod.).

Design intervenční skupiny

Intervence je v RCT hlavním předmětem zájmu. Hodnotí se její vliv na zdravotní stav ve srovnání s placebo intervencí nebo jinou formou kontroly. Rozdíl vlivů intervenční a KS je udáván jako velikost účinku (effect size) zkoumané intervence [9,10]. Pro základní orientaci v intervencích používaných k léčbě LBP uvádíme tři jednoduché charakteristiky:
– jaká intervence byla aplikována (graf 3),
– jak často (graf 4),
– po jak dlouhou dobu (graf 5).

Nejčastěji (29/66 studií) byly hodnoceny cvičební intervence. Z konkrétních forem se nejčastěji vyskytovaly různé verze progresivního zatěžování v podobě aerobního nebo odporového tréninku zaměřeného na svaly trupu a dol-

Graf 4. Studie ze souboru podle frekvence, s jakou je intervence poskytována.
Graph 4. Studies from the set according to the frequency with which the intervention is provided.
Graf uvádí odkazy na konkrétní studie z analyzovaného souboru 66 publikovaných prací.
Nezařaditelná studie: součástí studie jsou dvě nezávislé intervence, z nichž jedna je přístup k webové aplikaci po dobu 6 měsíců, druhá je telefonát po 8 týdnech a druhý telefonát po 12 týdnech [103].



Graf 5. Studie ze souboru podle délky intervenčního období.
Graph 5. Studies from the set by length of intervention period.

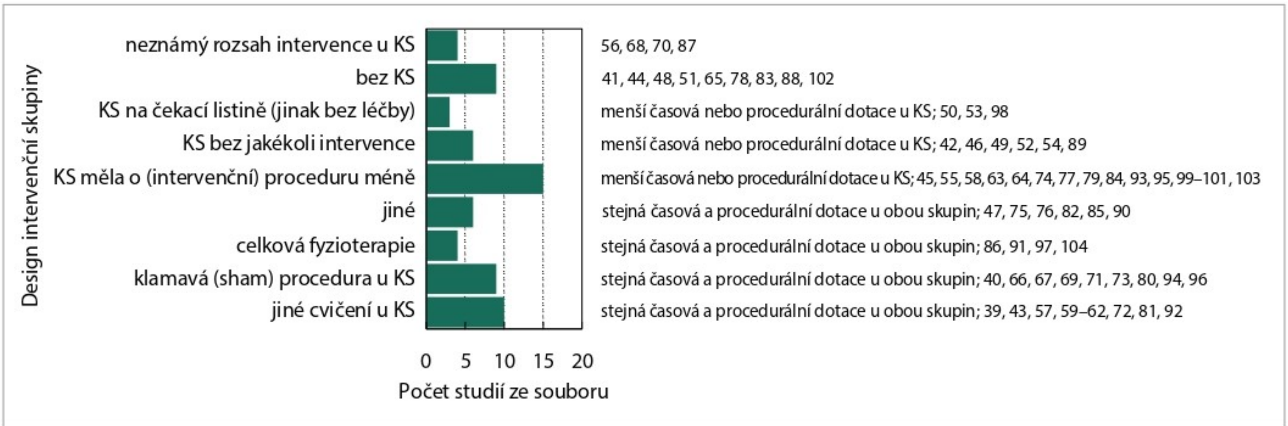
Graf uvádí odkazy na konkrétní studie z analyzovaného souboru 66 publikovaných prací.

ních končetin. V některých případech (4/66) bylo intervencí stupňované cvičení vedeno dle kognitivně behaviorálních postupů – tyto případy jsou uvedeny v obou kategoriích. Nejčastější délka sledovaného období, během kterého intervence probíhala, byla 6–9 týdnů (19/66 studií), nejčastější frekvence sledované intervence byla 2× týdně (15/66).

Design kontrolní skupiny

Zásadním nástrojem RCT je KS. Zavedením KS do studie uznáváme limity naší schopnosti změřit a správně interpretovat všechny vlivy na sledovaný parametr. Např. často nedokážeme určit význam jednotlivých proměnných (věk, pohlaví, stadium nemoci, spontánní uzdravení atd.) na zkoumaný parametr (např. subjektivně vnímaná bolest).

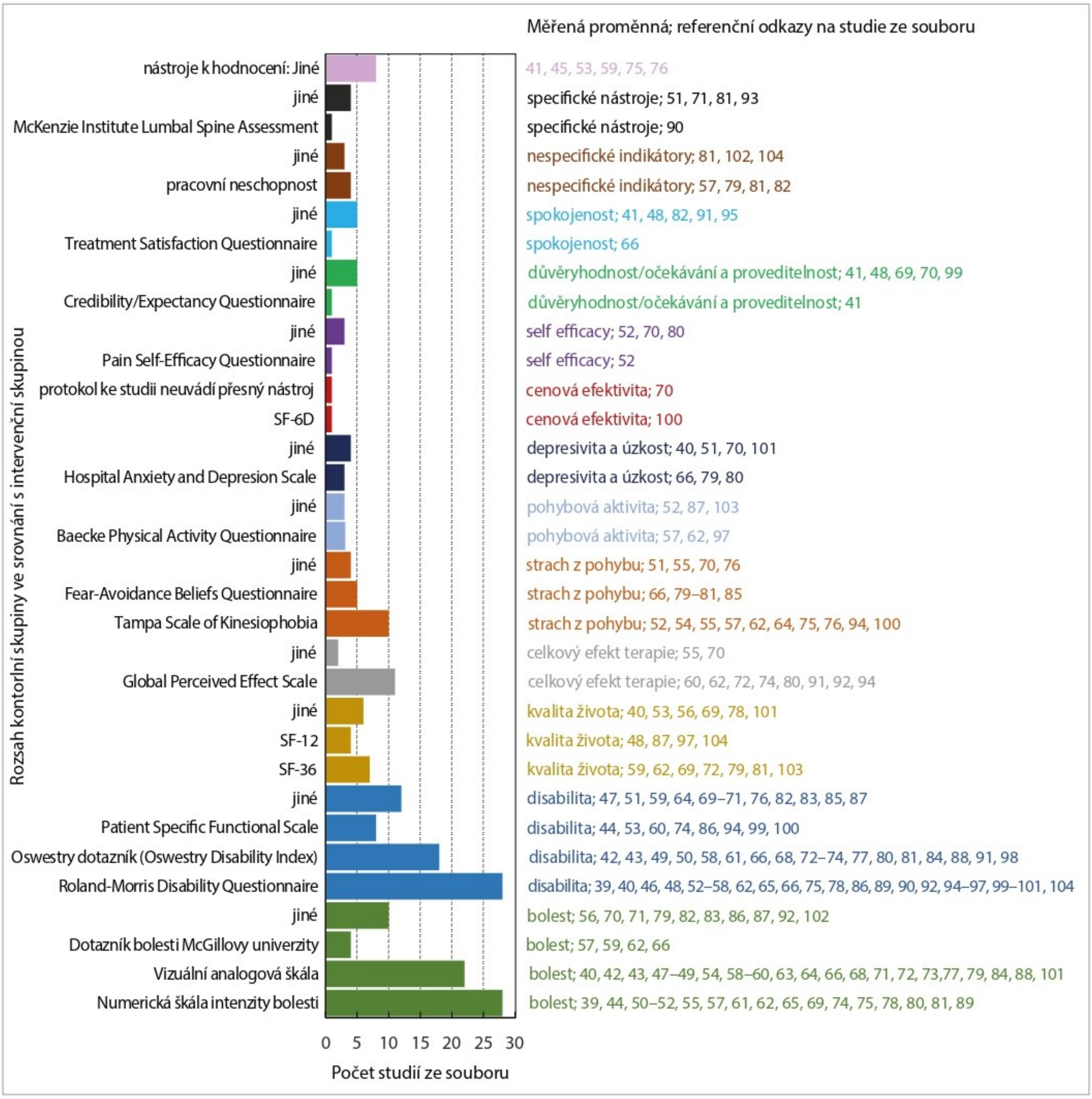
Do KS zařazujeme jedince se stejnou diagnózou a se srovnatelnými demografickými parametry (pohlaví, věk, body mass index (BMI)), event. s dalšími charakteristikami, které mohou výsledky ovlivnit (vzdělání, pracovní zařazení, sport atd.), jako do intervenční skupiny. Následně obě skupiny vystavíme co nejsrovnatelnějším vlivům. Rozdíl bude jen ve zkoumané „účinné látce“. Účinnou látkou se rozumí cokoli od molekuly léčiva po komplexní, např. cvičební postupy. V případě, že skupiny byly iniciálně srovnatelné ve všech charakteristikách a byly podrobeny stejným vlivům (až na sledovanou „účinnou látku“, resp. intervenci), lze předpokládat, že případné rozdíly pozorované v následujících měřeních byly dosaženy sledovanou intervencí [9] nebo náhodou. Pravděpodobnost náhodného výsledku lze stanovit



Graf 6. Studie ze souboru podle designu kontrolní skupiny.
Graph 6. Study from the set according to the design of the control group.

Graf uvádí odkazy na konkrétní studie z analyzovaného souboru 66 publikovaných prací.
Do kategorie „jiné“ byly zařazeny všechny výsledky, jejichž četnost výskytu byla < 3, patří sem: škola zad [76,90], příručka [82,85], jiný (než intervenční) feedback [75], injekce jiné (než intervenční) látky [47].

KS – kontrolní skupina



Graf 7. Studie ze souboru podle použitých dotazníkových měřících metod (PROM).

Graph 7. Studies from a set according to the questionnaire measurement methods used (PROM).

Do kategorií „jiné" byly zařazeny:

Bolest: plán měřit bolest pomocí PROM v dopředu publikovaném protokolu, ale nástroj neuvádí [70,82,87], Pain Perception Scale a Main Pain Staging System [71], Defense & Veterans Pain Rating Scale [56], Dallas Pain Questionnaire [79], Graded Chronic Pain Scale a Örebrö musculoskeletal pain questionnaire [86], Sciatica Bothersomeness Index [102], StarT back screening tool classification [92], Low Back Pain Rating Scale [83];

Disabilita: Quebec Back Pain Disability Scale [64,70,85], Pain Disability Index [71,76], plán měřit disabilitu pomocí PROM v dopředu publikovaném protokolu, ale nástroj neuvádí [82,87], Waddel Disability Index [59], Pain Disability Questionnaire [47], Hanover Functional Ability Questionnaire [51], Functional Rating Scale [69], Low Back Pain Rating Scale [83];

Kvalita života: PROMIS [53,56], HRQOL-4 [101], PedsQL [78], EQ-5D [40], NASS [69];

Celkový efekt terapie: Patient Global Impression of Change [55], plán měřit celkový efekt terapie pomocí PROM v dopředu publikovaném protokolu, ale nástroj neuvádí [70];

Strach z pohybu: mezi „jiné" patří: Pain Catastrophizing Scale [55,76], plán měřit kinesiofóbii a katastrofizaci pomocí PROM v dopředu publikovaném protokolu, ale nástroj neuvádí [70], Pain Vigilance and Awareness Questionnaire [76], Patient Anxiety Symptom Scale [51];
Pohybová aktivita: Rapid Assessment of Physical Activity [52], Global Physical activity Questionnaire [103], plán měřit pohybovou aktivitu pomocí PROM v dopředu publikovaném protokolu, ale nástroj neuvádí [87];
Depresivita a úzkost: Patient Health Questionnaire [40,101], Geriatric Depression Scale [51], plán měřit depresivitu a úzkost pomocí PROM v dopředu publikovaném protokolu, ale nástroj neuvádí [70];
Self-efficacy (do češtiny někdy jako „sebeúčinnost" nebo „sebedůvěra"): Pain Self-Efficacy Questionnaire [52], Falls-Efficacy Scale-International [52], plán měřit self-efficacy pomocí PROM v dopředu publikovaném protokolu, ale nástroj neuvádí [70], Chronic Pain Self-Efficacy Scale [80];
Důvěryhodnost, očekávání a proveditelnost: vedlejší účinky [69], adherence [41,99], plán měřit proveditelnost [48], kredibilitu a očekávání [70] pomocí PROM v dopředu publikovaném protokolu, ale nástroj neuvádí;
Spokojenost: plán měřit spokojenost pomocí PROM v dopředu publikovaném protokolu, ale nástroj neuvádí [48,82,91,95], Numeric Treatment Satisfaction Scale [41];
Nespecifické indikátory LBP: spotřeba analgetik [81,104], znovuobjevení bolesti, operace, epidurální obstřik [102];
Specifické nástroje (vlastních pro určitou metodu či studii): vlastní dotazník [71,81], Interview [51,93], Movement System Impairment Classification System [81];
Jiné nástroje PROM hodnocení než v grafu a v legendě výše uvedené: Borgova škála [75], Revised Illness perception questionnaire a Pain Vigilance and Awareness Questionnaire [76], Intrinsic Motivation Inventory a adherence k proceduře [41], Coping Strategies Questionnaire [53], The Multidimensional Assessment of Interoceptive Awareness [59], General Causality Orientation Scale a Learning Self-regulation Questionnaire a Health Care Climate Questionnaire [45].

PROM – patient reported outcome measures, LBP – bolesti bederní páteře

pomocí statistických metod. Největším rizikem zůstává možnost, že některé významné proměnné nebyly identifikovány a kontrolovány.

Ve zdravotnickém výzkumu existuje riziko, že samotný kontakt personálu s probandy pozmění výstupní data. Typické vlivy jsou např. množství věnované péče, času, vyšetřování, testování, zpětné vazby apod. Nehledě na konkrétní obsah může mít samotný kontakt měřitelný efekt [9]. Obecně platí, že čím více proměnných chceme kontrolovat, tím méně by se intervenční a KS měly lišit (v charakteristikách probandů, v poskytnuté péči atd.).

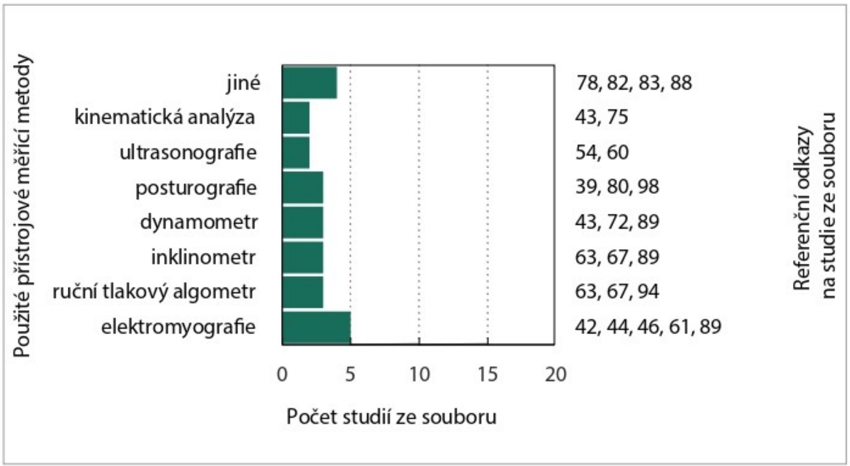
V prostředí farmaceutických dvojitě zaslepených RCT bývá užíváno klasické placebové KS [11]. V případě placebo kontroly nepřidáváme žádnou proměnnou navíc. Na rozdíl od farmaceutických studií nemohou studie v rehabilitaci využít klasického placeba. Kvalitní design KS je proto skutečnou výzvou [9]. Důležitou roli hraje časová a procedurální dotace, tj. zda je KS podrobena stejnému množství procedur o stejné intenzitě, frekvenci a délce jako skupina intervenční. Většinou je „účinná látka" nahrazena jiným postupem či klamavou (sham) procedurou. Některé studie „účinnou látku" nenahrazují, tj. KS má o tuto proceduru méně, event. KS není podrobena žádným procedurám. Graf 6 uvádí nejčastější typy intervencí aplikovaných u KS v rámci 66 analyzovaných studií.

Měřicí metody, měřené veličiny

V souboru analyzovaných 66 studií bylo v zásadě použito tří typů měřicích (hodnoticích) metod. Jednalo se o měřicí metody přístrojové, klinické testy a o tzv. výsledky sdělované pacientem (PROM – patient reported outcome measures). PROM byly nejčastějším způsobem měření efektu intervence a zároveň pokrývaly nejširší spektrum měřených proměnných (graf 7). Nejčastěji měřenými proměnnými byly disabilita a bolest. Oba parametry byly nějakým způsobem hodnoceny v naprosté většině (58/66) studií v souboru. Bolest byla nejčastěji hodnocena pomocí numerické škály bolesti (NRS – numeric rating scale) (29/66) a vizuální analogové škály (VAS) (22/66), z dotazníkových škál hodnotících disabilitu byl zcela nejfrekventovaněji použit Roland-Morris Disability Questionnaire (28/66). Hodnocení dalších proměnných již nebylo pravidlem (graf 7). V některých studiích docházelo k měření jedné proměnné více nástroji, jak je patrné z grafů 8 a 9. Přístrojové měření (graf 8) bylo využito podstatně méně často než PROM, nejčastěji byla provedena elektromyografie vyšetření (5/66); z klinických testů (graf 9) byla nejčastěji použita Thomayerova zkouška (5/66). Přístrojové a klinické hodnocení je tedy oproti PROM v analyzovaných 66 studiích podstatně méně používané.

Diskuze a doporučení

Cílem tohoto přehledu bylo shromáždit a kvantitativně zhodnotit informace o dílčích složkách designu, které v současné době používají autoři klinických studií se zaměřením na výzkum LBP. Výsledky šetření ukazují značné rozdíly mezi studiemi ve všech složkách designu. Lze předpokládat, že častěji používané metody studií publikovaných v renomovaných časopisech jsou kvalitnější nebo poskytují jinou výhodu. Samotná četnost výskytu však kvalitu metody nezaručuje. O kvalitě designu rozhoduje řada faktorů, jako

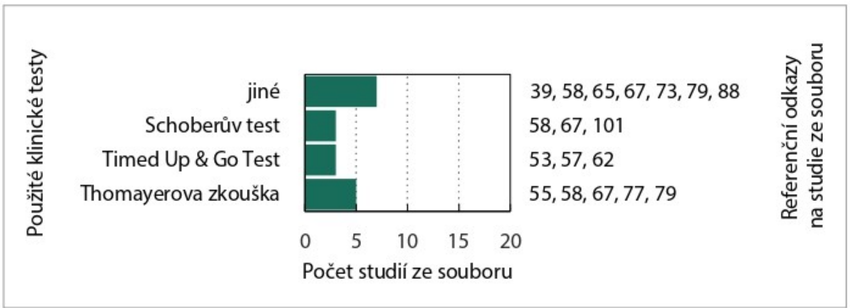


Graf 8. Studie ze souboru podle použitých přístrojových měřících metod.
Graph 8. Studies from a set according to the instrumental measurement methods used.

Graf uvádí odkazy na konkrétní studie z analyzovaného souboru 66 publikovaných prací.
Do kategorie „jiné" byly zařazeny všechny výsledky, jejichž četnost výskytu byla < 2, patří sem: akcelerometr [78], elektroencefalografie [82], rentgen [83], magnetická rezonance [88].

je počet probandů, existence KS, srovnatelnost intervenční a KS, kvalita použitých měřicích nástrojů, zaslepenost a mnoho dalších. Některé části designu (velikost vzorku probandů) je vždy žádoucí přizpůsobit specifickým podmínkám. U jiných (definice sledované populace pomocí inkluzivních a exkluzivních kritérií, výběr měřicí metody) lze doporučit, aby se autoři drželi zvyklostí v oboru. Usnadní tím porovnávání výsledků mezi studiemi a tvorbu review studií.

Podívejme se, jak by vypadal design RCT, pokud bychom ho vytvořili na zá-



Graf 9. Přehled studií v souboru podle klinických testů použitých k hodnocení.
Graph 9. Overview of studies in the set according to the clinical tests used for evaluation.

Graf uvádí odkazy na konkrétní studie z analyzovaného souboru 66 publikovaných prací.

Do kategorie „jiné" byly zařazeny všechny výsledky, jejichž četnost výskytu byla < 3, tj.: Trendelenburgova zkouška (one-legged stand test) [39,58], Deep Muscle Contraction Scale a Clinical Test for Thoracolumbar Dissociation a Pasive Lumbar Extension test [65], Sit and reach test a Back saver sit and reach test [67], Slump test [88], Ottova inklinační a Ottova reklinační vzdálenost a Index to floor – úklon [73], Sorensen and Ito test [79].

kladě nejvyšší četnosti výskytu dílčích částí designu ve zkoumaném souboru.

1. *Počet probandů:* 72 (36 probandů v intervenční a 36 v KS).
2. *Kritéria inkluze:* věk 18–65 let, cLBP (déle než 3 měsíce), počáteční míra bolesti nejméně 3/10 na 11stupňové (0–10) NRS (nebo 30 mm/100 mm dle škály VAS) [12,13], schopnost porozumět slovnímu projevu i psanému textu v lokálním jazyce, ve kterém je studie prováděna.
3. *Kritéria exkluze:* operace (páteře, dolních končetin, pánve nebo břicha), jiná probíhající léčba nebo rehabilitace (vč. masáží, akupunktury aj.), jiné diagnostikované vybrané patologie jako např. těžká degenerativní onemocnění páteře nebo nosných kloubů, těhotenství, jiné bolesti, bolest nad úrovní 12. žebra nebo pod úrovní gluteálních rýh, příznaky kořenového dráždění, strukturální deformita (skolióza, jiné deformity páteře a dolních končetin), neurologický deficit, revmatické onemocnění, onkologické onemocnění, fraktura (páteře nebo dolních končetin), jiné závažné onemocnění, kardiorespirační onemocnění, kontraindikace k intervenci, akutní infekce, psychiatrické onemocnění, psychosomatické onemocnění.
4. *Intervenční skupina:* cvičební program (aerobní cvičení nebo posilování svalů trupu a dolních končetin; cvičení kontroly pohybu, protahovací cvičení zaměřené na svaly trupu a dolních končetin) 2× týdně po dobu 8 týdnů. Cvičení probíhá pod vedením školených fyzioterapeutů v kombinaci s autoterapií.
5. *KS:* totéž co intervenční skupina, ale bez zkoumané intervence.
6. *Měřicí metody:* NRS [12,13], Roland-Morris Disability Questionnaire [14–16], SF-36 [17–20], škála celkového pocitu změny [21,22], Tampa Scale of Kinesiophobia [23–25].

Výše uvedená kritéria můžeme považovat za výchozí model designu RCT zaměřené na výzkum cLBP s cílem zjistit vliv na bolest, disabilitu a kvalitu života. Tento model lze doplnit o přehled vybraných doporučení ze současných guidelines [6,26,27]. CONSORT 2010 byl sice sepsán za účelem zlepšení kvality reportu (popisu) designu a průběhu studie, může však být nápomocen už při tvorbě designu. Např. se jedná o určení velikosti souboru probandů [6]. V rámci tvorby designu RCT lze doporučit ještě následující klíčové body:

1. Ještě před zahájením náboru probandů definovat inkluzivní a exkluzivní kritéria. Probandy, kteří inkluzivní kritéria nesplňují, vyřadit a vést o takových případech dokumentaci. Tyto konkrétní příklady lze uvést v reportu podrobněji, event. reportovat v rámci tabulky (např. „flow diagram" doporučovaný CONSORT). Vysíláme tak signál, že vyřazený pacient je reálná osoba a osoby skutečně byly vyřazovány, pokud se u nich objevila potenciálně ovlivňující komorbidita nebo jiný důvod k exkluzi. V rámci inkluzivních kritérií je třeba definovat spodní hranici pro počáteční (baseline) míru disability nebo bolesti.
2. V ideálním případě je žádoucí použít tzv. stratifikovanou randomizaci. Pomocí této metody rozřadíme probandy do skupin tak, že v každé ze skupin bude stejné zastoupení významných proměnných. Zároveň o zařazení konkrétního probanda do jedné ze skupin nebude rozhodovat ani výzkumník, ani samotný proband. To je důležité, protože některé proměnné (např. věk, pohlaví, BMI, počáteční míra bolesti aj.) totiž mohou ovlivňovat výsledný efekt terapie. Pokud by se v důsledku tendenčního výběru nebo náhody dostalo do jedné ze skupin např. výrazně více mladých osob, důvěra v prezentované výsledky, které mají reprezentovat celou populaci, bude logicky podkopána. Stratifikovaná randomizace s sebou nicméně přináší několik komplikací, kterým je nutné věnovat pozornost. Nejvýznamnějším problémem jsou organizační nároky. Je obtížné zajistit tento stratifikovaný způsob randomizace, pokud dopředu neznáme charakteristiky všech probandů. Což většinou neznáme, protože probandi jsou zpravidla do studie nabíráni postupně. Vhodnou alternativou může být tzv. adaptivní randomizace podle nezávislých proměnných (covariete adaptive randomization). V rámci této metody rozřadíme část (polovinu) probandů zcela náhodně. Druhou část probandů již cíleně rozřazujeme podle zvoleného klíče tak, aby výsledné skupiny byly srovnatelné ve svých počátečních charakteristikách. Výsledná skupina, do které je proband v druhé části výběru zařazen, je výsledkem předchozího náhodného rozřazení první části probandů a rozřazovacího klíče. Vůle probanda ani výzkumníka tak opět nemá na randomizaci vliv. U obou randomizačních metod je množství nezávislých proměnných, podle nichž můžeme probandy rovnoměrně rozdělit do skupin, omezené a závisí na celkovém počtu probandů [28]. Principy randomizace nejsou složité, je však třeba v základní míře pochopit několik možností randomizace a zvolit ten správný způsob pro daný výzkum. K orientaci v této problematice dobře poslouží přehledové články Kanga et al. [29] a Kima et al. [30].
3. Obě intervence (experimentální i kontrolní) je nutné detailně popsat jak kvalitativně, tak kvantitativně (délka každé intervence, frekvence, délka celého sledovaného období, intervence pod vedením terapeuta vs. autoterapie atd.) tak, aby bylo možné je zopakovat [6]. V popisu cvičebního protokolu by měly být obsaženy i prvky motivačních strategií, pravidel pro zvýšení zátěže, jiných necvičebních součástí terapie vč. edukace probanda atd. [27]. Zejména je vhodné rozpracovat a uvést kritéria pro zvýšení, nebo snížení zátěže u cvičebních programů. Z hlediska medicíny založené na důkazech není možné bez detailního popisu intervence a kontrolní intervence kriticky zhodnotit zjištěnou velikost účinku [26].
4. Při designování intervenční skupiny je vhodné dodržovat existující doporučení publikovaná v Template on Intervention Description and Replication [26], je-li intervence cvičební, existuje rozšířený checklist Consensus on Exercise Reporting Template [27].
5. Dodržet maximálně shodné podmínky a charakteristiky intervenční a KS. Na místo intervence je optimální u KS zařadit klamavou proceduru (nepředpokládáme klinicky významný účinek), je-li to možné, což lze považovat za kvalitnější kontrolu, než je alternativní intervence. Pro optimalizaci etické stránky RCT je možné KS nabídnout aktivní intervenci po uplynutí sledovaného období, péče tak nebude redukována, pouze odložena. Je nutné mít na paměti, že KS zásadně ovlivňuje výsledky studie. Poddimenzované KS mohou být příčinou překvapivě významného účinku intervenční skupiny, jak uvádí Levack et al. v trefně nazvaném článku: Ve srovnání s čím? v anglickém originále Compared to what? [9].
6. Volit standardní a v odborné literatuře často reportované způsoby měřicích metod, které lze snadno replikovat v budoucích studiích na podobné téma. Nezbytným minimem je měření disability, bolesti, kvality života a celkového efektu terapie [31,32].
7. Disabilitu je vhodné měřit zejména pomocí Roland-Morris Disability Questionnaire [15–17] nebo Oswestry Disability Index [14,15,33,34]. Oba dotazníky jsou zavedené, kvalitní, prakticky totožné v klinimetrických vlastnostech originálních verzí a dostupné v českých verzích.
8. Totéž platí pro škálu VAS a NRS v případě hodnocení intenzity bolesti [12,13]. Je-li k tomu důvod, je možné hodnotit bolest pomocí české verze krátké formy dotazníku bolesti McGillovy univerzity. Dotazník obsa-

huje hodnocení intenzity bolesti pomocí škály VAS, ale také dalších dimenzí bolesti [35,36].

9. Nemělo by chybět hodnocení kvality života pomocí SF-36 nebo SF-12 [17–20].
10. Pro hodnocení celkového efektu terapie existuje např. česká verze sedmistupňové škály Patient Global Impression of Change [21].

Jedním ze zásadních limitů ve výzkumu LBP jsou vysoké nároky na počet probandů účastnících se studie. Důvodem je velké měřítko PROMs. K zachycení jakékoli (větší než chyba měření) změny je zapotřebí poměrně velkého posunu v rámci škály. Je proto potřeba velké změny u velkého množství probandů (nebo častěji středně velké změny u opravdu velkého množství probandů), abychom získali průkazná data. Nástroje schopné zachytit menší změny spolehlivě (např. přístrojové měřicí metody) obvykle neměří relevantní parametry, které jsou v přímém vztahu ke sledovaným veličinám, jako je bolest, disabilita a kvalita života. Zatím neexistuje měřitelný parametr intervalového charakteru (lineárně rostoucí), který by měl příčinnou souvislost s LBP, jako má např. tlak krve s rizikem vzniku kardiovaskulárního onemocnění. LBP je multifaktoriální diagnóza, její zkoumání vyžaduje kombinaci výzkumných metod různého druhu. PROMs nicméně v nejbližší budoucnosti nepochybně zůstanou základní měřicí metodou výzkumu LBP.

Důležitý vliv má též stanovení optimálního počtu probandů. Příliš malý počet zvyšuje pravděpodobnost, že zjištěný rozdíl vznikl náhodně, nikoli v důsledku sledované intervence [37]. Příliš velký počet může vést k tomu, že zjištěný rozdíl bude sice nenáhodný, ale natolik malý, že nebude mít význam pro praxi. Tedy zjistíme statisticky významný, ale klinicky nevýznamný rozdíl. I z toho důvodu je vhodné vedle statistické významnosti (hodnota p) uvádět také významnost věcnou, např. výpočtem Cohenova d [10]. Příliš velké studie jsou v některých případech zbytečně náročné, drahé a mohou vystavovat pacienty v KS neetickému omezení péče [6,7,38]. Optimální počet probandů by měl být odhadnut ještě před zahájením studie. Lze tak učinit výpočtem. Vzorce se liší dle designu studie a charakteru měřených veličin. V souvislosti s touto tematikou lze doporučit např. monografii Hulleyho et al. [37], z české literatury pak monografii Hendla [8].

Závěr

Článek předkládá analýzu 66 studií hodnotících efekt různých typů rehabilitačních intervencí u pacientů s diagnózou cLBP, publikovaných v prestižních vědeckých časopisech. Na základě této literární rešerše doporučujeme postup, jak optimálně připravit design studie, která je zaměřena na vyšetření a terapii pacientů s cLBP. Článek by měl sloužit zejména studentům fyzioterapie a rehabilitace, kteří připravují výzkumné projekty na dané téma pro zpracování bakalářských, diplomových a dizertačních prací.

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7. Závěr

Rešeršní část této disertační práce shrnuje poznatky o posturálních funkcích trupových svalů a roli IAP při stabilizaci páteře. Dále informuje o možnostech jejich objektivního hodnocení. Stabilita páteře je zajištěna kosterním, vazivovým a svalovým aparátem. Právě svalová funkční stabilizace je dlouhodobě velmi důležitým a často diskutovaným tématem v rehabilitaci. Je zajišťována koordinovanou aktivitou bránice, PD, břišními a zádovými svaly. Výsledkem této svalové souhry je zvýšení IAP, což má za následek stabilizování celého trupu. IAP má také schopnost odlehčit páteř při axiálním zatížení. Tato automatická posturální reakce je důležitá zejména při fyzickém zatížení jako je například zvedání břemene.

Ve vědeckém výzkumu je pro objektivizaci posturální role IAP nutné tento tlak měřit přístrojově. K tomu slouží invazivní i neinvazivní postupy. Často se používají rektální nebo gastrické sondy, které jsou velmi nepříjemné pro vyšetřovaného, a celkově jsou tato měření finančně nákladná a časově náročná. K hodnocení funkce svalů trupu se využívá elektromyografické nebo ultrasonografické vyšetření. Tyto přístupy nám ale podávají informace spíše o lokálních svalových kontrakcích a neinformují nás o celkové globální posturální reakci trupu.

V klinické praxi se posturální stabilita trupu nejčastěji hodnotí palpací tenze břišní stěny v oblasti třísla a v TLS. Palpační vyšetření je však subjektivní a jeho využití ve výzkumu je tudíž problematické. Proto byly v rámci praktické části této disertační práce sestrojeny tlakové senzory, které skrze monitoraci napětí břišní stěny hodnotí posturální aktivitu trupových svalů. Lze je využít na základě výsledků studií popisujících změny napětí břišní stěny, respektive jeho zvýšení v reakci na zvýšení IAP. Potvrzují to jak studie provedené na kadaverech, tak novější studie in vivo, včetně studie „Intra-abdominal pressure correlates with abdominal wall tension during clinical evaluation tests“ prezentované v rámci této disertační práce.

V rámci pilotního výzkumu jsme pomocí tlakových senzorů Ohmbelt představili nový neinvazivní způsob objektivního hodnocení aktivity břišní stěny v různých posturálních situacích. Pomocí senzorů se podařilo prokázat, že ke zvýšení aktivity břišní stěny dochází oproti klidovému dýchání v situaci s externí zátěží a při volní aktivaci břišní stěny. Proto mohou být senzory využity jako objektivní vyšetřovací metoda nebo jako biofeedback v tréninku aktivace trupové stabilizace. Nejdůležitějším výstupem předložené disertační práce je potvrzení silné korelace mezi tenzí břišní stěny a změnami IAP. Tenze břišní stěny v oblasti TLS a tříselného vazu byla měřena pomocí tlakových senzorů DNS Brace, hodnoty IAP byly monitorovány pomocí HRAM. Prokázali jsme, že monitorováním tenze břišní stěny můžeme nepřímo sledovat změny IAP a potažmo tak hodnotit stabilizaci páteře. Následná studie zjišťovala spolehlivost mezi vyšetřujícími terapeuty a korelaci mezi tenzí břišní stěny měřené tlakovými senzory se subjektivním hodnocením aktivity břišní stěny při palpačním vyšetření zkušenými terapeuty. Identifikovali jsme konkrétní testy hodnocení posturální stabilizace, které lze považovat za dostatečně spolehlivé v klinické praxi. Test volního zvýšení nitrobřišního tlaku v oblasti TLS a třísla spolu s testem flexe kyčelního kloubu jsou spolehlivé při klinickém palpačním vyšetření.

Představili jsme také kazuistiku vrcholového kanoisty trpícího LBP. Terapie byla zaměřena na správnou trupovou stabilizaci pomocí IAP. Pozitivní efekt terapie byl hodnocen objektivně pomocí tlakových senzorů snímajících aktivitu břišní stěny, palpačním vyšetřením aktivity břišní stěny terapeutem a subjektivním vnímáním bolesti pacientem pomocí VAS. Nová metodika prezentovaná v rámci publikované kazuistiky využívající kombinaci přístrojového, klinického a subjektivního hodnocení terapie může sloužit jako podklad pro budoucí rozsáhlejší studie u pacientů s LBP.

V další studii jsme hodnotili efekt fyzioterapie zaměřené mimo jiné na správnou trupovou stabilizaci u 10 pacientek s anorektální dysfunkcí. Měření funkce pánevního dna pomocí HRAM ukázalo statisticky nevýznamné zlepšení. Hodnocení pomocí dotazníku SMIS ukázalo signifikantní zlepšení subjektivního stavu pacientek a kvality jejich života po konzervativní terapii. Na uvedené experimentální studie má návaznost i rešeršní publikace „Jak připravit optimální design klinické studie zaměřené na chronické bolesti bederní páteře: doporučení na základě literární rešerše prací publikovaných v letech 2014–2019“. Ačkoliv se jedná o článek v českém neimpaktovaném periodiku, jedná se o významnou metodologickou pomůcku pro studenty fyzioterapie a rehabilitace, kteří připravují výzkumné projekty na dané téma pro zpracování bakalářských, diplomových a disertačních prací.

Tato disertační práce v rámci rešeršní části a v navazujících šesti výzkumných pracích představuje ucelený pohled na posturální funkci břišních svalů a IAP a také možnosti objektivního hodnocení této aktivity a pozitivní efekt terapie zaměřené na aktivaci optimální trupové stabilizace u pacientů s poruchami pohybového aparátu. Novou metodiku hodnocení posturální stabilizace, kterou prezentujeme v rámci této disertační práce, bude možné využít v navazujících rozsáhlejších experimentálních pracích a v další výzkumné činnosti.

8. Souhrn

Postural and respiratory function of the abdominal muscles: A pilot study to measure abdominal wall activity using belt sensors: V pilotním výzkumu jsme změřili tlakovými senzory v oblasti třísla a v oblasti trigonum lumbale superius (TLS) skupinu 35 zdravých mladých probandů ve třech posturálně odlišných situacích v sedě: při klidovém dýchání, v situaci s přidanou externí zátěží a v situaci korigovaného dýchání. Prokázali jsme signifikantní zvýšení míry aktivace břišní stěny v situaci s externí zátěží (držení činky v horních končetinách) a při korigovaném dýchání (volní maximální natlakování břišní stěny) oproti klidovému nekorigovanému respiračnímu stereotypu. V rámci práce byl prezentován nový metodický postup objektivizace míry tenze břišní stěny pomocí nového přístroje Ohmbelt. Nová metoda měření pomocí senzorů prezentovaná v rámci tohoto výzkumu může sloužit jako objektivizace efektu terapie i jako terapeutický biofeedback klientů s bolestí zad a s jinými funkčními patologiemi pohybového systému, a to za různých posturálních situací z důvodu jednoduchého upevnění a malé velikosti senzorů.

Intra-abdominal pressure correlates with abdominal wall tension during clinical evaluation tests: Stěžejním výzkumem této disertační práce bylo stanovit sílu korelace mezi tenzí břišní stěny a nitrobřišním tlakem (IAP). 31 zdravých probandů bylo změřeno pomocí simultánní anorektální manometrií (high resolution anorectal manometry – HRAM) a přístroje DNS Brace, který měří tenzi břišní stěny pomocí čtyř tlakových senzorů upevněných na vnitřní stranu trupové ortézy. Testováno bylo pět situací – klidové dýchání, Valsalvův manévr, Müllerův manévr, brániční test (volní zvýšení IAP) a statické držení činky v předpažených horních končetinách. Ve všech pěti měřených situacích jsme potvrdili silnou korelaci hodnot tenze břišní stěny IAP. Prokázali jsme, že IAP se zvyšuje při posturálním zatížení a úměrně ke zvýšení IAP dochází k expanzi břišní stěny v oblastech nad tříselnými vazy a v oblasti trigonum lumbale suprius. Lze tedy tvrdit, že monitorováním tenze břišní stěny lze nepřímo hodnotit velikost nitrobřišního tlaku, který se významně podílí stabilizaci páteře.

Correlation between palpatory assessment and pressure sensors in response to postural trunk tests: V tomto výzkumu bylo hodnoceno 25 zdravých probandů ve věku 20 až 25 let přístrojem DNS Brace a posturálními testy podle konceptu Dynamické Neuromuskulární Stabilizace. Cílem práce bylo porovnat, zda existuje korelace mezi objektivně přístrojově měřenou mírou aktivace břišní stěny a subjektivním hodnocením kvality trupové stabilizace, a jaká je palpační spolehlivost mezi 2 terapeuty. Testováno bylo pět posturálně odlišných situací vycházejících ze sedu – test dechového stereotypu, volní aktivace nitrobřišního tlaku (intra-abdominal pressure – IAP) v tříslech, volní aktivace IAP v oblasti trigonum lumbale superius (TLS). Střední až silnou korelaci mezi hodnotami naměřenými na senzorech a při palpaci jsme identifikovali ve třech klíčových klinických testech: test nitrobřišního tlaku (volní natlakování břišní dutiny v oblasti třísla), brániční test (volní natlakování břišní dutiny v oblasti TLS) a test flexe v kyčelním kloubu. Tyto testy lze proto považovat za spolehlivé pro hodnocení posturální stabilizace, pokud je provádí zkušený vyškolený terapeut. Zároveň tyto tři testy vykazovaly střední nebo silnou korelaci mezi dvěma vyšetřujícími (inter-rater reliability), a to pro palpaci i aspekci.

The significance of intra-abdominal pressure on postural stabilization: A low back pain case report: Efekt léčby pacienta s bolestmi bederní páteře (low back pain – LBP) zaměřené na trupovou stabilizaci je prezentován na kazuistice vrcholového kanoisty. Terapie vedla ke zlepšení dle klinického palpačního vyšetření, v objektivním hodnocením pomocí trupových senzorů DNS Brace a v subjektivním zlepšení ve vnímané bolesti hodnocené pomocí vizuální analogové škály. Použitá metodika subjektivního, klinického i přístrojového měření efektu terapie u pacienta s LBP může sloužit jako podklad pro budoucí rozsáhlejší kontrolované studie s více probandy.

Anorectal dysfunction in multiple sclerosis patients: A pilot study on the effect of an individualized rehabilitation approach: Efekt terapie využívající mimo jiné nácvik trupové stabilizace, resp. regulace nitrobřišního tlaku, byl zkoumán na skupině deseti pacientek trpících anorektální dysfunkcí v důsledku roztroušené sklerózy. Pacientky podstoupily rehabilitační intervenci po dobu šesti měsíců. Efekt terapie byl objektivizován pomocí anorektální manometrie (high resolution anorectal manometry – HRAM). Vyšetření HRAM sice neprokázalo signifikantní zlepšení (nejspíše z důvodu malého počtu probandů), nicméně pozorovali jsme pozitivní trend, tj. statisticky nevýznamné zlepšení hodnot HRAM po šestiměsíční terapii. Signifikantní zlepšení bylo potvrzeno v subjektivním hodnocení pacientek pomocí dotazníku St. Mark's Fecal Incontinence Scores.

How to prepare an optimal design of a clinical study focusing on chronic low back pain: guidelines based on a review of scientific papers published in 2014–2019: Článek předkládá analýzu 66 studií hodnotících efekt různých typů rehabilitačních intervencí u pacientů s diagnózou chronických bolestí zad (LBP) publikovaných v prestižních vědeckých časopisech. Na základě této literární rešerše je doporučen postup, jak optimálně připravit design studie, která je zaměřená na vyšetření a terapii pacientů s LBP. Článek by měl sloužit zejména studentům fyzioterapie a rehabilitace, kteří připravují výzkumné projekty na dané téma pro zpracovaní bakalářských, diplomových a disertačních prací.

9. Summary

Postural and respiratory function of the abdominal muscles: A pilot study to measure abdominal wall activity using belt sensors: In this pilot study, measurements of a group of 35 healthy young participants in groin and trigonum lumbale superius (TLS) in three posturally different sitting situations: at rest, in a situation with added external load, and in a situation of instructed breathing. It was demonstrated that a significant increase of abdominal wall activation occurred in the situation of external load (holding the barbell in the arms) and also during instructed breathing (free maximum pressure of the abdominal wall) as compared to the rest with uncorrected respiratory stereotype. Also part of this pilot study, a new methodical procedure for objectifying the level of abdominal tension using a new Ohmbelt device was presented. This new measurement method using unique sensors presented in this research can be used as objectification of the effect of therapy as well as therapeutic biofeedback with clients with low back pain and other functional pathologies of the musculoskeletal system in various postural situations due to easy attachment and small sensor size.

Intra-abdominal pressure correlates with abdominal wall tension during clinical evaluation tests: The aim of this dissertation research was to determine the level of correlation between intra-abdominal pressure (IAP) and abdominal wall tension. 31 healthy participants were measured using simultaneous high resolution anorectal manometry (HRAM) and a DNS Brace instrument. DNS Brace measures abdominal wall tension using four pressure sensors placed on the inner wall of the torso orthosis. Five different situations were tested – calm breathing, Valsalva maneuver, Müller's maneuver, diaphragm test (voluntary voluntary pressurization of the abdominal cavity) and static holding of the barbell in arms. In all five monitored situations, it was confirmed that there is a strong correlation between intra-abdominal pressure and abdominal wall tension. It was shown that rise of abdominal pressure increases with increased demands on postural stability, and that with an increase with IAP, there is a proportional expansion of the abdominal wall above the inguinal ligaments and in the trigonum lumbale superius area. Thus, it can be argued that by monitoring the tension of the abdominal walls, it is possible to indirectly assess the level of the intra-abdominal pressure, which can significantly improves the stabilization of the spine.

Correlation between palpatory assessment and pressure sensors in response to postural trunk tests: In this study, 25 healthy participants with ages between 20 to 25 years were evaluated with the DNS Brace device and postural tests according to the DNS concept. The aim of this study was to compare whether there is a correlation between objectively evaluations of abdominal wall activation and subjective evaluation of trunk stabilization quality. Five posturally different situations in sit were tested – breath stereotype test, voluntary activation of intra-abdominal pressure (IAP) in the groin, voluntary activation of (IAP) in the trigonum lumble superius (TLS) area and Arm elevation test. It was identified that there is a moderate to strong correlation between DNS Brace pressure sensors and palpation values in three key clinical trials: intra-abdominal pressure test (voluntary voluntary pressurization of the abdominal cavity in the groin area), diaphragmatic test (voluntary voluntary pressurization of the abdominal cavity in the TLS area) and hip flexion test. These tests can therefore be considered reliable for assessing postural stabilization when performed by an experienced trained therapist. At the same time, these three tests showed a medium or strong correlation between the two investigators (inter-rater reliability, both for palpation and obseravtion.

The significance of intra-abdominal pressure on postural stabilization: A low back pain case report: This case study demonstrates the effect of the treatment of a a top level canoeist patient with low back pain (LBP) utlizing trunk stabilization. Throughout the therapy there was improvements in clinical palpation, in objective evaluation using DNS Brace trunk sensors and also in subjective improvement in perceived pain as assessed by visual analogue scale. The used methodology of subjective, clinical and instrumental measurement of the effect of therapy in patient with LBP can serve as a basis for future larger controlled studies with more participants.

Anorectal dysfunction in multiple sclerosis patients: A pilot study on the effect of an individualized rehabilitation approach: The effect of therapy using trunk stabilization training respectively intra-abdominal pressure regulation was studied in a group of ten patients suffering from anorectal dysfunction due to multiple sclerosis. The patients underwent rehabilitation intervention for six months. The effect of the therapy was objectified using high resulution anorectal manometry (HRAM). Although the HRAM test did not show a significant improvement (probably due to the small number of participants), we nevertheless observed a positive trend, i.a a statistically insignificant improvement in HRAM values after six months of therapy. Significant improvement was confirmed in the subjective evaluation of patients using the St. Mark's Fecal Incontinence Scores questionnaire.

How to prepare an optimal design of a clinical study focusing on chronic low back pain: guidelines based on a review of scientific papers published in 2014–2019: The article presents an analysis of 66 studies evaluating the effect of different types of rehabilitation interventions in patients with a diagnosed chronic low back pain (LBP), published in prestigious scientific journals. Based on this literature search, a procedure is recommended for optimally preparing a study design that focuses on the examination and therapy of patients with chronic LBP. The article could possibly be used by students of physiotherapy and rehabilitation preparing research projects on a given topics for the elaboration of bachelor's, diploma and dissertation thesis.

10. Literatura

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11. Přehled publikační činnosti autora

a) s impakt faktorem

1. **NOVAK, Jakub,** JACISKO, Jakub, BUSCH, Andrew, CERNY, Pavel, STRIBRNY, Martin, KOVARI, Martina, PODSKALSKA, Patricie, KOLAR, Pavel and KOBESOVA, Alena, 2021. Intra-abdominal pressure correlates with abdominal wall tension during clinical evaluation tests. Clinical Biomechanics. August 2021. Vol. 88, pp. 105426. DOI 10.1016/j.clinbiomech.2021.105426. **IF$_{2020-2021}$:2.063**

2. **NOVAK, Jakub,** BUSCH, Andrew, KOLAR, Pavel and KOBESOVA, Alena, 2021. Postural and respiratory function of the abdominal muscles: A pilot study to measure abdominal wall activity using belt sensors. Isokinetics and Exercise Science. 8 April 2021. Vol. 29, no. 2, pp. 175–184. DOI 10.3233/IES-203212. **IF$_{2020-2021}$: 0.519**

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4. KOVARI, Martina, STOVICEK, Jan, **NOVAK, Jakub,** HAVLICKOVA, Michaela, MALA, Sarka, BUSCH, Andrew, KOLAR, Pavel and KOBESOVA, Alena, 2021. Anorectal dysfunction in multiple sclerosis patients: A pilot study on the effect of an individualized rehabilitation approach. NeuroRehabilitation. 7 November 2021. pp. 1–11. DOI 10.3233/NRE-210226. **IF$_{2020-2021}$:2,138**

b) bez impakt faktoru

1. **NOVAK, Jakub,** JACISKO, Jakub, STVERAKOVA, Tereza, JUEHRING, David D., SEMBERA, Martin, KOLAR, Pavel and KOBESOVA, Alena, 2022. The significance of intra-abdominal pressure on postural stabilization: a low back pain case report. Slovak Journal of Sport Science. 17 January 2022. Vol. 7, no. 2, pp. 3–18. DOI 10.24040/sjss.2021.7.2.3-18.

2. PECKA, Vaclav, **NOVAK, Jakub,** MACHAC, Stanislav and KOBESOVA, Alena, 2022. How to prepare an optimal design of a clinical study focusing on chronic low back pain: guidelines based on a review of scientific papers published in 2014–2019. 2022. Vol. 24, no. 2. DOI doi: 10.48095/ccrhfl20221.

Přednášky a plakátová sdělení na odborných setkáních

2018: aktivní přednášející na konferenci (XX. Teplické ortopedické sympozium): Rehabilitace po reimplantaci TEP kolenního kloubu

2019: aktivní přednášející na konferenci (3. Športová Konferencia); Využití a objektivizace nitrobřišního tlaku v rámci posturálních funkcí

2021: aktivní přednášející na konferenci (5. Športová Konferencia); Fyzioterapie u oštěpařů

2022: aktivní přednášející na DNS Motolské konferenci 2022; DNS a DSP: Výzkumné DNS projekty v rámci doktorského studijního programu Kineziologie a rehabilitace