第 49 卷 第 8 期
2022 年 8 月

湖南大学学报（自然科学版）
Journal of Hunan University (Natural Sciences)

Vol. 49 No. 8
August 2022

Open Access Article https://doi.org/10.55463/issn.1674-2974.49.8.26

Assessment of Thoracic Kyphosis Using Flexicurve Ruler after Open Heart Surgery: A Cross-Sectional Study

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Abstract: In literature, the development of spinal deformities was reported after surgical intervention for congenital heart disease using thoracotomy and sternotomy incisions in children; however, there are not enough data regarding the incidence of spinal kyphosis after open-heart surgery in adults. This study aimed to determine the impact of open-heart surgery using median sternotomy incision on the sagittal plane thoracic spine curve and pulmonary functions after open-heart surgery. A cross- sectional study was conducted on 100 participants (53 ± 9.43 years), who underwent open heart surgery using median sternotomy. The spinal kyphotic curve was evaluated using a Flexicurve ruler and spirometry parameters [forced vital capacity (FVC), forced expiratory volume in the first second ($FEV_{1)}$ and ratio of forced expiratory volume in the first second to forced vital capacity (FEV_1/FVC)] were evaluated before and one week after open-heart surgery. The comparison between the preoperative and postoperative measurements of the variables under study was performed using the paired t-test. Statistical significance was set at ($P < 0.05$). The results revealed a significant increase in the dorsal kyphotic curve (9.75 ± 2.32) and a significant decrease in all spirometry parameters under study [(FVC: 2.12 ± .77); (FEV_1:1.55 ± .64) and (FEV_1/FVC: 0.72 ± .13)] with an alpha level of ($P < 0.05$). There is a high incidence of exaggerating the sagittal plane thoracic spine curvature (thoracic kyphosis), and reduction in the pulmonary functions after open-heart surgery using median sternotomy incision.

Keywords: open heart surgery, spinal kyphosis, assessment, pulmonary functions.

心脏直视手术后使用弹性曲线尺评估胸椎后凸：一项横断面研究

摘要: 文献报道，儿童先天性心脏病通过开胸和胸骨切口进行手术干预后脊柱畸形的发展；然而，关于成人心脏直视手术后脊柱后凸畸形发生率的数据还不够。本研究旨在确定使用胸骨正中切口进行心脏直视手术对矢状面胸椎曲线和心脏直视手术后肺功能的影响。对 100 名参与者（53 ± 9.43 岁）进行了一项横断面研究，他们接受了胸骨正中切开术的心脏直视手术。

Received: May 12, 2022 / Revised: June 19, 2022 / Accepted: July 2, 2022 / Published: August 30, 2022

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使用 弹性曲线 标尺和肺活量参数[用力肺活量(FVC)、第一秒用力呼气量(FEV1)和第一秒用力呼气量与用力肺活量之比(FEV1/FVC)评估脊柱后凸曲线]在心脏直视手术前和一周后进行评估。使用配对吨检验对所研究变量的术前和术后测量值进行比较。统计显着性设定为（磷 ˂0.05）。结果显示背侧后凸曲线显着增加(9.75 ± 2.32)和研究中的所有肺活量测定参数显着降低[(FVC: 2.12 ± .77);(FEV1:1.55 ± .64)和(FEV1/FVC: 0.72 ± .13)]，α水平为(磷 < 0.05)。使用胸骨正中切口进行心脏直视手术后，夸大矢状面胸椎曲率（胸椎后凸）和肺功能降低的发生率很高。

关键词: : 心脏直视手术、脊柱后凸、评估、肺功能.

1. Introduction

Open-heart surgery has many postoperative complications, such as pulmonary, neurologic, vascular, musculoskeletal, and psychiatric [1-3]. Cardiac surgery is a challenge for the patients and the whole cardiac surgery team before and after the operation the same as during the surgery [4]. Heart-surgery procedures usually require median sternotomy, which is functionally better tolerated than lateral thoracotomy, since it preserves the pleural space, minimal interruption to the chest wall, less trauma, and negligible lung compression make the sternotomy a relatively benign procedure [5, 6]. During the median sternotomy the chest wall is disrupted and a gap between the two margins of the sternum is generated [7]. A study was conducted to determine the incidence of spinal deformity in patients after thoracotomy and sternotomy for congenital heart disease in children, it was concluded that spinal deformities, including scoliosis and/or hyperkyphosis, were found in 38% of the younger age patients [1].

Median sternotomy has a negative effect on thoracic spin stability [8]. Also, the wound pain after median sternotomy decreases the pulmonary function, and impaired lung mechanics [9]. Physical and social problems of spinal kyphosis, including a decrease in height, a protruded abdomen, back pain, digestive problems, impairment of respiratory function, decreased mobility, poor self-image, and loss of independence leading to a decreased quality of activity of daily living [10]. Fatigability occurs easily in an individual with kyphosis and he has considerable difficulty with activities requiring an upright posture or exercise tolerance, such as walking, climbing stairs, housework, and reaching overhead [11]. To measure spinal kyphosis, investigators have begun using specialized equipment such as the Flexicurve ruler, DeBrunner’s kyphometer, roentgenographs, and inclinometer [12-14]. Since kyphosis is a risk factor for loss of function, it is beneficial to have a technique for measuring kyphosis that can be applied in clinical practice [11]. A study was conducted to assess the test–retest reliability of the measurement of thoracic kyphosis using the flexicurve ruler in individuals with osteoporosis, it was concluded that the use of the flexicurve ruler for measuring kyphosis in elderly with osteoporosis was valid and reliable and that the measurement of thoracic kyphosis using the flexicurve may be useful in examining the degree of kyphosis [15].

Based on the above information, we hypothesized that open heart surgery using a median sternotomy incision is associated with developing thoracic kyphosis deformity that reduces the pulmonary functions consequently. This study aims to investigate the impact of open-heart surgery using median sternotomy in developing thoracic kyphosis and to investigate the association between kyphosis and the reduction of pulmonary functions after surgery.

2. Materials and Methods

2.1. Study Design

Cross-sectional study design.

2.2. Sample Size Calculation

A priori sample size calculation was performed using G*Power (version 3.1.0) with the test family set at (t-test), alpha level of 0.05, a confidence level of 95%, study power of 95% and effect size of 0.8. These assumptions generated a sample size of 100 participants considering a possible 10-20% drop-out rate.

2.3. Participants

A convenient sample of one hundred adult patients (60 males and 40 females) was recruited from South Valley University hospital between April 2020 and December 2021. The participants were aged 45-60 years, and they were listed for open heart surgery using single sternotomies. The flowchart of the study participants is displayed in Figure 1.

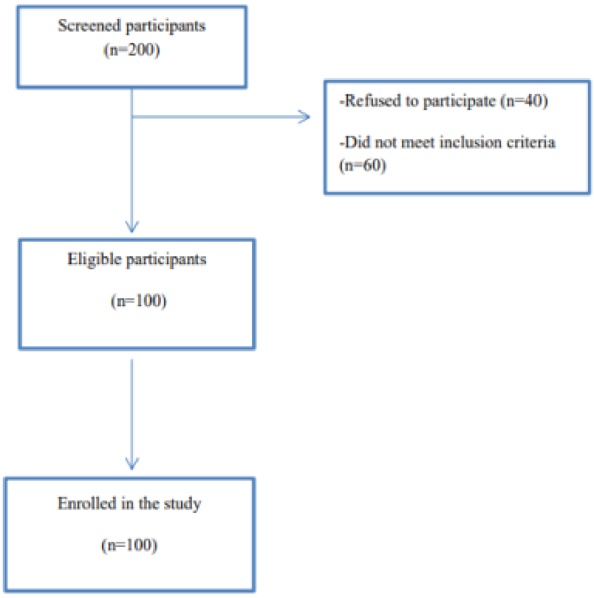

Fig. 1 Flowchart of the study participants

The exclusion criteria were as follows: 1) patients who underwent thoracotomy or combined sternotomy and thoracotomy; 2) patients with any spinal malalignment or deformities; 3) lower extremity deformities or leg length discrepancy that could affect spinal alignment; 4) history of previous cardiothoracic surgeries; 5) history of previous surgeries in the spine; 6) history of lower extremity fractures or surgeries that could affect the spine alignment.

The current study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the ethical committee at the Faculty of Physical Therapy, South Valley University, Qena, Egypt, with the following approval number [REC-SVU-01030019]. Written informed consent was obtained from all participants before enrollment in the study. All participants were informed about the study objectives before participation. Participants were informed about their right to withdraw from the study at any time.

2.4. Procedures

The patients were assessed twice; the first time was before the operation as a preoperative examination. The second was on the day of discharge from the hospital. The spinal kyphotic curve and pulmonary functions (FVC, $FEV_1$and FEV_1/FVC) were examined by a physical therapist who was trained for all assessments for 10 days before this study and was blinded for the study objectives.

Spinal kyphosis: Using the Flexicurve ruler (Staedtler Mars Inc, Nurnberg, Germany), which is a flexible band of lead metal covered with a smooth sheath of plastic approximately 60 cm long. The ruler could be bent in only one plane and keeps the shape to which it is bent. The patients were instructed to stand up straight and tall as much as they can with their hands rested on the back of a chair. Then, they were instructed to rest their hands beside them keeping their back straight, and then after that thoracic kyphosis was measured using a Flexicurve ruler.

To trace the measured thoracic curve, the ruler was placed flat on paper and its outline was traced using a pencil. We measured the length of thoracic kyphosis (l) by tracing a straight line between C7 and T12 on a paper and was measured in cm. To measure the height of the thoracic kyphosis (h) in cm, a perpendicular line was drawn from the highest point in the traced thoracic curve to the point at which it intersected the straight line drawn from C7 to T12 (Figure 2).

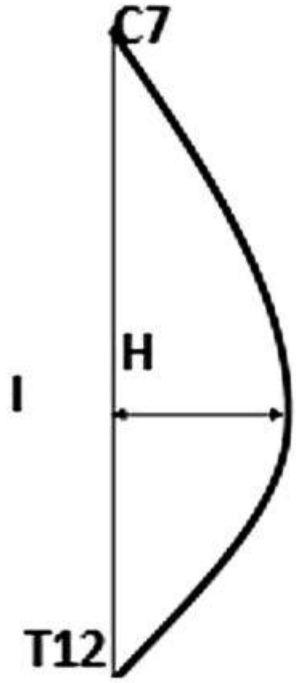

Fig. 2 Calculation of Kyphotic index [kyphotic index= (h/l) x 100]

The index of kyphosis was measured by applying the formula: (h/l) x 100. In this study, the distance from C7 to T12 was measured using the Flexicurve ruler. The purpose of measuring the thoracic spine from (C7 to T12) in the current study was to isolate the specific region of interest.

Pulmonary function tests: We used a spirometer tubing to assess pulmonary function, including forced expiratory volume in the first second (FEV_1), forced vital capacity (FVC) and FEV_1/FVC [16]. The patients were taught the following procedure of doing PFT: (1) Patient preparation consisted of explaining the purpose of the test and how it would be done with keeping the explanation brief and in simple terms; (2) A patient is given own clean mouthpiece fixed on the valve at the end of the spirometer tubing. (3) The patient sat in a comfortable position with feet firmly on the floor and a nose clip on the patient's nose; (4) The patient was shown the proper chin neck position: chin should be elevated and the neck slightly extended, this position should be maintained throughout the forced expiratory procedures, the patient should not bend the chin to the chest. (5) The mouthpiece is placed into the patient mouth, the patient is asked not to bite down on mouthpiece, lips should be sealed tightly and the tongue should not stick out into the mouthpiece. (6) The patient is asked to breathe in fully (must be absolutely full) then expire forcefully and rapidly as much as possible through the mouthpiece. (7) At least three technically acceptable maneuvers should be obtained, ideally with less than 0.15-L variability for FEV1 (and FVC) between the highest and second highest result (obtain the best of 3). Each individual test is acceptable if it meets the following acceptability and repeatability criteria.

2.5. Statistical Analysis

The normality of data distribution was analyzed with the Shapiro-Wilk test. As the data followed a normal distribution, the comparison between the pre-operative and postoperative measurements of the variables under study was performed using the paired t-test. P value of < 0.05 was considered as statistically significant. The effect size was interpreted according to Cohen's Classification of effect size [small = 0.2; moderate= 0.5; large = 0.8].

3. Results

The demographic data of all participants are reported in Table 1.

Table 1 Demographic data of the study participants (n = 100)

Variables	**Mean ± SD**
Age (years)	53 ± 9.43
Height (cm)	169 ± 7.94
Weight (kg)	84 ± 6.83
BMI	29.41 ± 2.33
Gender	
Male	60 (60%)
Female	40 (40%)

Continuous data are expressed as mean ±Standard deviation; Categorical data are expressed as absolute number (percentage %)

Post-operative results revealed that there was a significant increase in the dorsal kyphotic curve. Moreover, there were significant statistical differences in the pulmonary functions under study between the pre- and post-operative results as shown in Table 2. The pre- and post-operative results of the Kyphotic index are reported in Table 2.

Table 2 Comparisons between pre- and post-operative variables under study

Variable	**Pre-operative (Mean ± SD)**	**Post-operative (Mean ± SD)**	**MD**	**t-value**	**P- value**	**Effect size (d)**	**Observed Power**
Kyphotic index	7.22 ± 2.12	9.75 ± 2.32	2.53	9.72	.001*	0.84	0.92
FVC (L)	2.26 ± .85	2.12 ± .77	0.14	2.1	.001*	1.6	0.98
FEV_1 (L)	1.87 ± .74	1.55 ± .64	0.32	4.92	.001*	0.92	0.96
FEV_1/FVC	0.82 ± .11	0.72 ± .13	0.55	5.33	.001*	0.89	0.95

Notes: Level of significance at P < 0.05.* = significant; MD: mean difference; d: Cohen's effect size; FVC: forced vital capacity, FEV_1: Forced expiratory volume in the first second; FEV_1/FVC: Forced expiratory volume in the first second to forced vital capacity

4. Discussion

This study was designed to determine the impact of open-heart surgery using median sternotomy in developing thoracic kyphosis and the effect of this deformity development on pulmonary functions (FVC, FEV and FEV_1/FVC).

In this study, the distance from C7 to T12 was measured using the flexicurve ruler. Previous studies have used Flexicurve to measure from the C7 spinous process to the L5–S1 junction [15], thus measuring both thoracic kyphosis and lumbar lordosis. The rationale for the extended reference points is that thoracic kyphosis resulting from osteoporosis is often associated with a compensatory increase in lumbar lordosis [15]. This hyperlordosis along with a more upright positioning of the sacrum has also been noted by [12]. Other researchers have also indicated that greater stiffness in the thoracic spine may produce compensatory changes in the more mobile lumbar region [16].

The results of this study revealed a high incidence rate of thoracic kyphosis and reduction of pulmonary function (FCV, FEV) after median sternotomy in open-heart surgery in adult. In our current study, comparing the mean values of Kyphotic index at pre-operative and post-operative evaluations for the patients; there was a statistically significant increase in the Kyphotic index by about (7.94 ± 2.12) after median sternotomy in open-heart surgery in adults, this was consistent with the result of [1], where a study was conducted to investigate the incidence of spinal deformity (scoliosis and thoracic kyphosis) in patients after thoracotomy and sternotomy for congenital heart disease and the authors concluded that high incidence rate of thoracic scoliosis and kyphosis occurs in children after median sternotomy in congenital heart diseases.

The results of a sternotomy procedure are associated with a high risk of chronic thoracic pain and represent a severe clinical problem [17]-[18]. One of these problems is reduction in dorsal spine ROM and instability of this region [19]. Surgical Pain and reduction of thoracic spine ROM can lead to a rounded shoulder, which will increase the probability of developing exaggerated thoracic kyphosis, and this what our study proved after sternotomy. An increase in thoracic kyphosis affects the reduction of pulmonary function as it was stated previously in a retrospective review [20] examined the relationship between preoperative pulmonary function and the Cobb angle, location of apical vertebrae and age in adolescent idiopathic scoliosis (AIS), this review [20] concluded that pulmonary function impairments was associated with spinal deformities (thoracic kyphosis and scoliosis).

Respiratory impairment was greater in the more cranially located kyphosis, specifically above the T10 level [21]. In this study, we examined the pulmonary function tests (FVC, FEV and FEV_1/FVC) pre- and post-operative and there was a significant reduction in all pulmonary functions under study and this was consistent with the previous study [22] that investigated pulmonary complications after the use of extracorporeal circulation in cardiopulmonary bypass patients and concluded a reduction in pulmonary functions after surgery [22].

Postoperative pulmonary complications are still a leading cause of adverse results after cardiac surgery and increased morbidity and mortality rate. Pulmonary function is significantly reduced in the immediate postoperative period and the reason for this impairment is multifactorial [23].

Our study results were also consistent with a previous study [19], which investigated the relationship between pain and pulmonary function reduction after median sternotomy and they concluded that pain has a significant effect on pulmonary function after median sternotomy. Similarly, the current study findings are online with the previous studies [24]-[25] that indicated a rapid drop in pulmonary function after mitral valve replacement surgeries in adults.

Strength and limitations:

The current study findings showed that increase in the kyphotic index and reduction in the pulmonary functions under study are most probably attributed to pain and large median sternotomy incision that have a positive effect on decreasing pulmonary function [26]-[27].

One of the main limitations of this study is that the convenience sampling method followed could have a limitation toward the generalization of the current study finding. Furthermore, the current study investigated the spinal kyphotic curve after open heart surgery only in a certain age group (45-60 years), so studying different age groups should be addressed in the future research.

5. Conclusion

The risk of developing thoracic kyphosis and reduction in the pulmonary functions after cardiac surgery using median sternotomy incision is high and is most probably attributed to incisional pain, impaired chest expansion and reduced inspiratory muscle power. Therefore, prevention and treatment of these causes is recommended to prevent pulmonary complications.

References

[1] HERRERA-SOTO J A, VANDER HAVE K L, BARRY-LANE P, & WOO A. Spinal Deformity after Combined Thoracotomy and Sternotomy for Congenital Heart Disease. *Journal of Pediatric Orthopaedics*, 2006, 26(2): 211-215.

[2] MANJI R A, et al. Seizures following cardiac surgery: the impact of tranexamic acid and other risk factors. *Canadian Journal of Anesthesia*, 2012, 59(1): 6-13.

[3] TUSMAN G, BÖHM S H, WARNER D O, & SPRUNG J. Atelectasis and perioperative pulmonary complications in high-risk patients. *Current Opinion in Anaesthesiology*, 2012, 25(1): 1-10.

[4] PATANÈ F, VERZINI A, ZINGARELLI E, and DI SUMMA M. Simultaneous operation for cardiac disease and lung cancer. *Interactive Cardiovascular and Thoracic Surgery*, 2002, 1(2): 69-71.

[5] WOODS LS, FROELICHER E S, MOTZER S. Cardiac Nursing. 4th ed. Philadelphia Pa: JB Lippincott, 2000.

[6] CHETTA, A., TZANI, P., MARANGIO, E., et al. Respiratory effects of surgery and pulmonary function testing in the preoperative evaluation. *Acta bio-medica: Atenei Parmensis*, 2006, 77(2): 69-74.

[7] RAGNARSDOTTIR, M., KRISTJANSDOTTIR, A., INGVARSDOTTIR, I., et al. Short term changes on pulmonary function and respiratory movement after cardiac surgery via median sternotomy. Scandinavian Cardiovascular Journal 2004, 38(1): 46-52.

[8] BRASILIENSE, L. B., LAZARO, B. C., REYES, P. M., et al. Biomechanical contribution of the rib cage to thoracic stability. *Spine*, 201136(26), E1686–E1693. https://doi.org/10.1097/BRS.0b013e318219ce84

[9] RONCADA, G., DENDALE, P., LINSEN, L., et al. Reduction in pulmonary function after CABG surgery is related to postoperative inflammation and hypercortisolemia. *International Journal of Clinical and Experimental Medicine*, 2015, 8(7): 10938–10946.

[10] LYDICK, E., ZIMMERMAN, S. I., YAWN, B., et al. Development and validation of a discriminative quality of life questionnaire for osteoporosis (the OPTQoL). *Journal of Bone and Mineral Research*, 1997;12(3): 456-63.

[11] RYAN, S. D., & FRIED, L. P. The impact of kyphosis on daily functioning. *Journal of the American Geriatrics Society*, 1997, 45(12), 1479–1486. https://doi.org/10.1111/j.1532-5415.1997.tb03199.x

[12] LUNDON K, LI A, & BIBERSHTEIN S. Interrater and intrarater reliability in the measurement of kyphosis in post-menopausal women with osteoporosis. *Spine*, 1998, 23(18): 1978-1985.

[13] SPENCER, L., FARY, R., MCKENNA, L., et al. Thoracic kyphosis assessment in postmenopausal women: an examination of the Flexicurve method in comparison to radiological methods. *Osteoporosis International*, 2019, 30(10), 2009–2018. https://doi.org/10.1007/s00198-019-05023-5

[14] BARRETT, E., LENEHAN, B., O'SULLIVAN, K., et al. Validation of the manual inclinometer and flexicurve for the measurement of thoracic kyphosis. *Physiotherapy Theory and Practice*, 2017, 34(4): 1-9.

[15] MANDAL A, & GANGULY S. Non-invasive Measurement of Thoracic Kyphosis and Lumber lordosis among Agricultural workers and Corporate Professionals (IT) using Flexicurve Ruler. *International Journal of Occupational Safety and Health*, 2019, 9(2): 37-44

[16] GALLUCCI, M., CARBONARA, P., PACILLI, A., et al. Use of Symptoms Scores, Spirometry, and Other

Pulmonary Function Testing for Asthma Monitoring. *Frontiers in Pediatric Journal*, 2019, 7(54): 1-12.
[17] KALSO E, MENNANDER S, TASMUTH T, & NILSSON E. Chronic post-sternotomy pain. *Acta Anaesthesiologica Scandinavica*, 2001, 45(8): 935-939.
[18] VAN GULIK L, JANSSEN LI, AHLERS SJ, et al. Risk factors for chronic thoracic pain after cardiac surgery via sternotomy. *European Journal of Cardio-Thoracic Surgery*, 2011, 40(6): 1309–1313.
[19] LIEBSCH C, GRAF N, & WILKE H J. Wire cerclage can restore the stability of the thoracic spine after median sternotomy: an in vitro study with entire rib cage specimens. *European Spine Journal*, 2017, 26(5), 1401-1407. https://doi.org/10.1007/s00586-016-4768-x
[20] JOHARI, J., SHARIFUDIN, M. A., AB RAHMAN, A., et al. Relationship between pulmonary function and degree of spinal deformity, location of apical vertebrae and age among adolescent idiopathic scoliosis patients. *Singapore Medical Journal*, 2016, 57(1), 33–38. https://doi.org/10.11622/smedj.2016009
[21] MCMASTER MJ, GLASBY MA, SINGH H, & CUNNINGHAM S. Lung function in congenital kyphosis and kyphoscoliosis. *Journal of Spinal Disorders & Techniques*, 2007; 20(3):203-8.
[22] HUFFMYER, J. L., & GROVES, D. S. Pulmonary complications of cardiopulmonary bypass. *Best Practice & Research. Clinical Anaesthesiology*, 2015, 29(2): 163-175. https://doi.org/10.1016/j.bpa.2015.04.002
[23] RONCADA, G., DENDALE, P., LINSEN, L., et al. Reduction in pulmonary function after CABG surgery is related to postoperative inflammation and hypercortisolemia. *International Journal of Clinical and Experimental Medicine*, 2015, 8(7): 10938–10946.
[24] HEGAZY FA, MOHAMED KAMEL SM, ABDELHAMID AS, et al. Effect of postoperative high load long duration inspiratory muscle training on pulmonary function and functional capacity after mitral valve replacement surgery: A randomized controlled trial with follow-up. *PloS One*, 2021, 16(8): e0256609.
[25] HASSAN AM, KAMEL SM, ABDELHAMID AS, et al. Short-term effect of inspiratory muscle training on pulmonary function after mitral valve replacement: Quasi-experimental study. *Physiotherapy Practice and Research*, 2022, 43(1): 55-61
[26] BAUMGARTEN, M. C., GARCIA, G. K., FRANTZESKI, M. H., et al. Pain and pulmonary function in patients submitted to heart surgery via sternotomy. *Brazilian Journal of Cardiovascular Surgery*, 2009, 24(4), 497-505. https://doi.org/10.1590/s0102-76382009000500011.
[27] RENAULT JA, COSTA-VAL R, ROSSETTI MB, HOURI NETO M. Comparison between deep breathing exercises and incentive spirometry after CABG surgery. *Brazilian Journal of Cardiovascular Surgery*, 2009; 24(2): 165-72 https://doi.org/10.1590/S0102-76382009000200012

参考文:

[1] HERRERA-SOTO J A、VANDER HAVE K L、BARRY-LANE P 和 WOO A. 先天性心脏病开胸联合胸骨切开术后脊柱畸形。儿科骨科杂志，2006，26（2）：211-215。
[2] MANJI R A 等人。心脏手术后癫痫发作：氨甲环酸和其他危险因素的影响。加拿大麻醉杂志，2012，59(1)：6-13。
[3] TUSMAN G、BÖHM S H、WARNER D O 和 SPRUNG J. 高危患者的肺不张和围手术期肺部并发症。麻醉学当前观点，2012, 25(1): 1-10.
[4] PATANÈ F、VERZINI A、ZINGARELLI E 和 DI SUMMA M. 心脏病和肺癌的同时手术。交互式心血管和胸外科，2002，1（2）：69-71。
[5] WOODS LS、FROELICHER E S、MOTZER S. 心脏护理。第 4 版。费城宾夕法尼亚州：JB 利平科特，2000。
[6] CHETTA，A.，TZANI，P.，MARANGIO，E.，等。术前评估中手术和肺功能检测的呼吸效果。生物医学学报：阿泰尼帕门西斯, 2006, 77(2): 69-74。
[7] RAGNARSDOTTIR, M., KRISTJANSDOTTIR, A., INGVARSDOTTIR, I., 等。胸骨正中切开心脏手术后肺功能和呼吸运动的短期变化。斯堪的纳维亚心血管杂志 2004, 38(1): 46-52。
[8] BRASILIENSE, L. B., LAZARO, B. C., REYES, P. M. 等。胸廓对胸部稳定性的生物力学贡献。脊柱，201136（26），E1686-E1693。https://doi.org/10.1097/BRS.0b013e318219ce84
[9] RONCADA，G.，DENDALE，P.，LINSEN，L.，等。CABG 手术后肺功能下降与术后炎症和高皮质醇血症有关。国际临床与实验医学杂志, 2015, 8(7): 10938–10946.
[10] LYDICK, E., ZIMMERMAN, S. I., YAWN, B., 等。骨质疏松症鉴别生活质量问卷(选择生活质量)的开发和验证。骨与矿物研究杂志，1997；12(3)：456-63。
[11] RYAN, S. D. 和 FRIED, L. P. (1997)。脊柱后凸对日常功能的影响。美国老年病学会杂志，45（12），1479-1486。https://doi.org/10.1111/j.1532-5415.1997.tb03199.x
[12] LUNDON K、LI A 和 BIBERSHTEIN S. 评估绝经后骨质疏松症妇女后凸畸形的评估者间和评估者内信度。脊柱, 1998, 23(18): 1978-1985.
[13] SPENCER, L., FARY, R., MCKENNA, L. 等。绝经后妇女的胸椎后凸评估：弹性曲线方法与放射学方法比较的检查。国际骨质疏松症，2019，30（10），2009-2018。https://doi.org/10.1007/s00198-019-05023-5
[14] BARRETT, E., LENEHAN, B., O'SULLIVAN, K. 等。手动测斜仪和弯曲曲线测量胸椎后凸的验证。物理治疗理论与实践, 2017, 34(4): 1-9.
[15] MANDAL A 和 GANGULY S. 使用弹性曲线标尺对农业工人和企业专业人员(它)的胸椎后凸和木材前凸进行无创测量。国际职业安全与健康杂志, 2019, 9(2): 37-44
[16] GALLUCCI，M.，CARBONARA，P.，PACILLI，A.，等。使用症状评分、肺活量测定和其他肺功能测试来监测哮喘。儿科前沿杂志，2019，7（54）：1-12。
[17] KALSO E、MENNANDER S、TASMUTH T 和 NILSSON E. 慢性胸骨切开术后疼痛。斯堪的纳维亚麻醉学学报, 2001, 45(8): 935-939。
[18] VAN GULIK L、JANSSEN LI、AHLERS SJ 等。胸骨切开心脏手术后慢性胸痛的危险因素。欧洲心胸外科杂志，2011，40（6）：1309–1313。
[19] LIEBSCH C、GRAF N 和 WILKE H J. 钢丝环扎可以恢复胸骨正中切开术后胸椎的稳定性：对整个胸腔标本的体外研究。欧洲脊柱杂志，2017，26（5），1401-1407。https://doi.org/10.1007/s00586-016-4768-x
[20] JOHARI J, SHARIFUDIN M A, AB RAHMAN A, 等

人。青少年特发性脊柱侧凸患者肺功能与脊柱畸形程度、顶椎位置及年龄的关系[J]. 新加坡医学杂志, 2016, 57(1), 33–38. https://doi.org/10.11622/smedj.2016009
[21] MCMASTER MJ、GLASBY MA、SINGH H 和 CUNNINGHAM S. 先天性脊柱后凸和脊柱后凸的肺功能。脊柱疾病与技术杂志, 2007; 20(3):203 8。
[22] HUFFMYER, J. L. 和 GROVES, D. S. 体外循环的肺部并发症。最佳实践与研究。临床麻醉学, 2015, 29(2): 163-175. https://doi.org/10.1016/j.bpa.2015.04.002
[23] RONCADA, G., DENDALE, P., LINSEN, L., 等。CABG 手术后肺功能下降与术后炎症和高皮质醇血症有关。国际临床与实验医学杂志, 2015, 8(7): 10938–10946.
[24] HEGAZY FA, MOHAMED KAMEL SM, ABDELHAMID AS, 等。术后高负荷长时间吸气肌训练对二尖瓣置换术后肺功能和功能能力的影响：随机对照试验及随访。公共科学图书馆一期, 2021 年, 16(8)：e0256609。
[25] HASSAN AM、KAMEL SM、ABDELHAMID AS 等。吸气肌训练对二尖瓣置换术后肺功能的短期影响：准实验研究。物理治疗实践与研究, 2022, 43(1): 55-61
[26] BAUMGARTEN, M. C., GARCIA, G. K., FRANTZESKI, M. H., 等。通过胸骨切开术接受心脏手术的患者的疼痛和肺功能。巴西心血管外科杂志，2009，24(4)，497-505。https://doi.org/10.1590/s0102-76382009000500011。
[27] RENAULT JA, COSTA-VAL R, ROSSETTI MB, HOURI NETO M. CABG 手术后深呼吸练习和激励性肺活量测定的比较。巴西心血管外科杂志，2009；24（2）: 165-72 https://doi.org/10.1590/S0102-76382009000200012